Final Report

VALUATION OF REDUCTIONS IN HUMAN HEALTH SYMPTOMS AND RISKS

Voiume 4

CONCEPTS AND APPROACHES TO THE VALUATION OF SERIOUS ILLNESS

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VALUATION OF REDUCTIONS IN HUMAN HEALTH SYMPTOMS AND RISKS

This is Volume 4 of a four volume report. The project undertakes an assessment and reconciliation of attempts to value reductions in human health risks,' and it develops new methods and estimates for these values. Volume 1 is the executive summmary. Volume 2 contains a comparative assessment of work on valuing health risks. Based on the assessment, a set of interim morbidity and mortality values applicable to effects of criteria air pollutants is developed. Volume 3 reports on a study developing and applying contingent valuation techniques to the types of light symptoms often attributed to air pollution. Volume 4 reports on the design of approaches for valuing serious or life threatening illnesses.

Abstract of Volume 4

CONCEPTS AND APPROACHES TO THE VALUATION OF SERIOUS ILLNESS

Volume 4 extends the analysis of health valuation to life threatening illness.

Section 4.2 considers alternative definitions of health and, for the study of serious illnesses resulting from environmental causes, concludes that a definition in terms of absence of symptoms should be used. The potential contributions of various pollutants to the risks of serious illnesses are reviewed, in order to choose which diseases should be studied and what ranges of risks are relevant. Specific measures of health status are evaluated including symptom description, self-assessment, health risk appraisal, health indexes and multi-attribute utility functions. The first three of these are recommended for contingent valuation studies.

Section 4.3 develops a life cycle explanatory framework for valuing reductions in life-threatening illness that guides the remainder of the study. Within this framework, longevity (i.e. mortality) and quality of life (as affected by morbidity) are considered together in a unified context. Young people, presented with improved prospects for greater health and longevity only after a long period of time, will heavily discount the benefits and will pay little, even though aware that their preferences many years hence will be different. Policies that promise a near-term benefit will be valued much more highly by people of any age. If people can easily substitute near term consumption for deferred consumption, they will place less value on additions to life expectancy. The capacity for consumption changes over the life cycle. An added year of life accompanied by high income or accumulated wealth, together with a high quality of leisure time, will be valued relatively highly. Latency is modelled within the life cycle framework.

Section 4.4 develops a model of choice under uncertain

preferences, bringing utility theory to bear on the problem of valuing small changes in events that are thought of only infrequently and may involve low probabilities of occurrence. The model is applicable to eontingent valuation approaches to serious illness. The model assumes environmental health risks are unfamiliar to most people, and that because people seldom have occasion to think carefully about them they are uncertain about their preferences concerning them. The model leads to twelve theorems for stimulating people to obtain improved knowledge about their preferences and to state valid, consistent risk reduction values.

Section 4.5 applies the preceding sections to contingent valuation of life threatening illness. A structure for an intensive interviewing process is developed, based on techniques of in-depth interviewing.

The proposed interview structure contains four modules. The first module concerns the repsondent's health experiences. The defensive measures module is the second module. The third module pertains to risk perception and risk behavior. This module teaches respondents basic notions of probability and conveys information about probabilities involved in health. Information is obtained about repsondent perceptions and attitudes towards risks.

Contingent valuation questions form the fourth module. The module begins with simple questions involving certainty scenarios and mortality only, after which serious illnesses are introduced. Then life path scenarios are introduced that combine morbidity and mortality in a life cycle setting. Respondents are asked to choose among and value the scenarios, first in a certainty and then an uncertainty setting.

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4.1. OVERVIEW

Volume 4 extends the analysis of health valuation to the domain of life threatening illness. It provides an original framework that can be used to obtain values of increased longevity and reduced risks of death from serious illness.

Section 4.2 provides a discussion of approaches to the measurement of health status. This section is a pre-requisite to determining how to measure health attributes whose value is to be estimated. Simple self-rating of health, definition of health as a good or a bad, broadness of definition extending to mental well being, disease specific definitions and symptom specific definitions are among the appraoches to health measurement that are considered. A central purpose is to consider which measures should be used in estimating values connected with life threatening illness, giving particular attention to health risks due to environmental pollutants. Extensions of previous approaches to health measurement are suggested.

Section 4.3 develops an explanatory framework to guide the estimation of values that result from reductions in life-threatening illness. This framework brings out how people's decisions regarding health and longevity depend on their life situations and streams of experiences that have developed over long periods of time. An important implication is that the quality of life and longevity are part of a single decision making process, and that they must be considered together in a unified context taking account of a peron's life cycle situation. The life cycle framework is at the heart of the remainder of the study. One of the challenges brought out by the framework is how to measure the value people place-on the reduction of threats to health that have their effects only after a latency period that may be many years in duration. Analysis of this problem is one of the contributions of section 4.3.

Section 4.4 provides the theoretical underpinnings to another aspect of the problem of valuing life threatening illness. It brings economic theory to bear on the problem of how people think about and value small changes in small probabilities of large damages to health or risk to life. A clear understanding of this process is essential to determining the benefits of environmental policies if a contingent valuation approach is to be used to estimate values. The problem has been widely recognized, but heretofore procedures to deal with it have been largely ad hoc. The theoretical perspective of the present study is that environmental health risks are unfamiliar to most people, and that because people seldom have occasion to think carefully about them they are uncertain about their preferences concerning them. Section 4.4 contains a series of theorems that have implications about efficient ways of stimulating people to obtain improved knowledge about their own risk preferences and to state valid, consistent risk reduction values.

Section 4.5 brings together and applies all of section 4 research on life threatening illness. A structure for an in-depth intensive interviewing process is developed, embodying refinements based on focus group experiments. The structure is composed of four modules.

The first module concerns the repsondents' health experiences. It establishes the health endowmment and prepares respondents to give detailed thought to their health preferences and values.

The defensive measures module is the second module of the in-depth interview framework. Defensive measures, or averting behavior, are an important part of many people's efforts to increase the probability of good health over the life cycle. They are evidence of a willingness to pay for improved life prospects. Reductions in defensive measures are a part of the benefits of reducing health risks. In some cases averting behavior entails increased expenditures (for example air conditioning), while in other cases reduced expenditures occur (for example reduced smoking).

The third module pertains to risk perception and risk behavior. The first part of this module addresses the problem of teaching people to grasp the concept of probability as it is manifested in environmental health problems. In the second part of this module, respondents are asked questions about their behavior toward risk and how they perceive the riskiness of a variety of life situations.

Contingent valuation questions form the fourth module. The contingent valuation questions increase in complexity, beginning with simple questions involving certainty scenarios and mortality only. Next, serious illnesses are introduced, and respondents are asked their willingness to pay to eliminate the risks of getting diseases. These questions are followed by life path scenarios that combine morbidity and mortality in a life cycle setting. Alternative life path possibilities are presented, and respondents are asked to choose among and value them, first in a certainty and then an uncertainty setting.

It is believed that the approach developed in section 4, and the extensive preparation for obtaining expressions of willingness to pay described in the modules, constitute an advance in survey research on the values of health improvements, and that intensive empirical applications are needed.

4.2. DEFINING AND MEASURING HEALTH OVER LIFE

4.2.1 Overview

Health measurement is an essential part of any analysis of the values that people derive from policies affecting health. Several different methods of health measurement have been employed in the literature. Self-assessment is the most widely used measure of health status. People are asked to rate their own health as excellent, good, fair or poor. This approach has been used in the Center for Health Administration Studies national surveys and in many smaller household surveys.

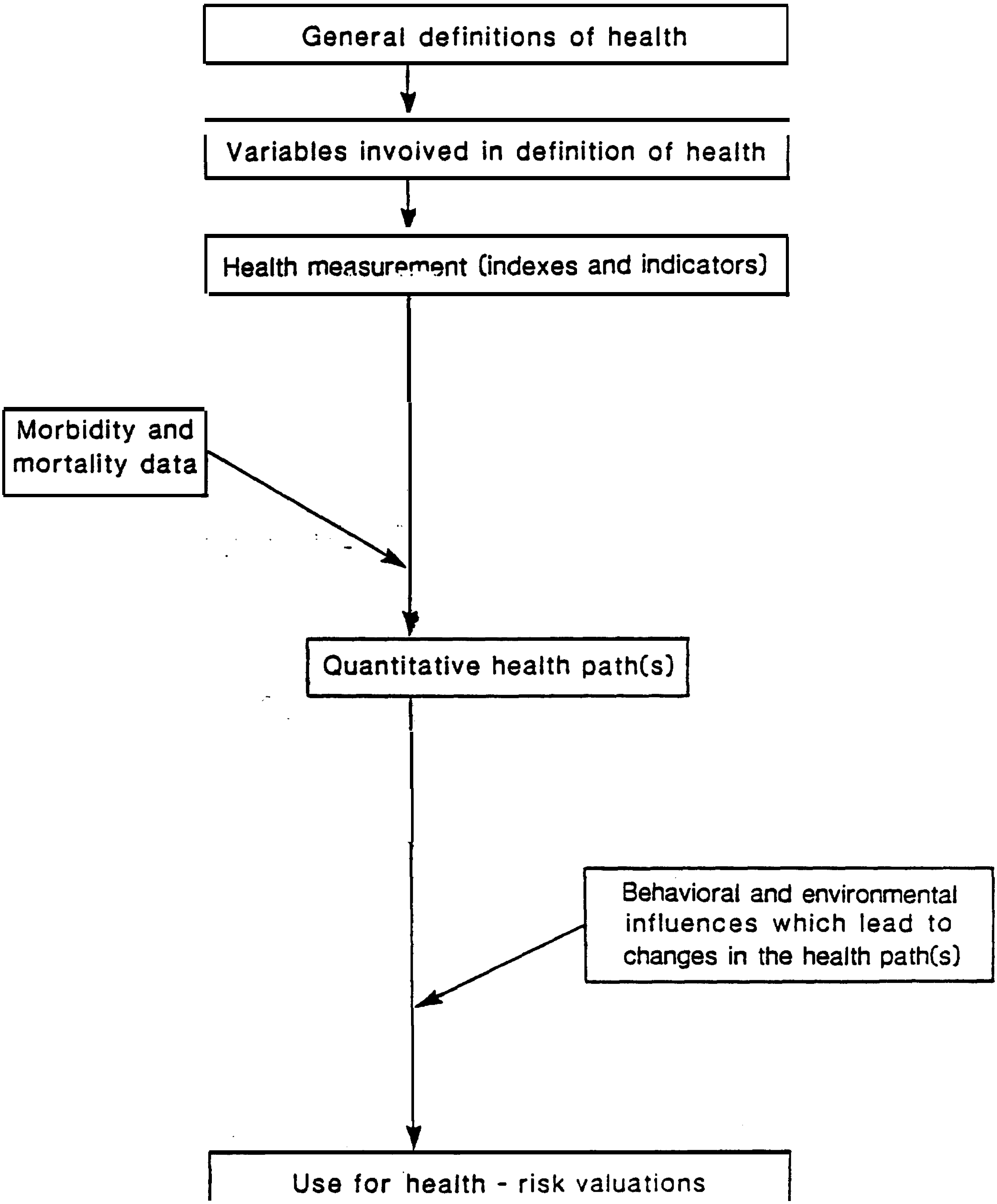
Other frequently used approaches include reports of restricted activity days, bed disability days, number and severity of symptoms experienced, number of chronic conditions, and the amount of pain experienced by the respondent during the past year. A variety of attitude questions have also been used, such as perceived effectiveness of health care [Fuchs, 1982, pp.144-145]. Studies of the demand for health care have utilized these measures of health status. These studies have included non-market health related activities as well as expenditures on medical care consumption. They have focused on such topics as price and income elasticities of demand and the effects of insurance on medical care consumption. Health status is often an important variable in explaining the demand for health care.

Recent work has emphasized that health is a multi-dimensional condition whose complexity should be represented in health studies in order to avoid bias in the measurment of price and income elasticities and other important variables. The multi-attribute utility function is an example of the multi-dimensional approach. A study of Torrence et al. [1982] represents health according to four dimensions: morbidity and physical activity; self care and role activity; emotional well-being and social activity; and health problems [Chestnut and Violette, 1984].

In studying values associated with life threatening illness in this study, it is necessary to define and measure health, choosing among the previous approaches and building on them where necessary. Figure 4-l depicts the progression from health definition to use of morbidity and mortality data and knowledge about influences on health, to measurements for health risk valuations. Drawing on this schema, the present section provides a critique of previous approaches and suggests extensions, giving attention to conceptual adequacy and practical considerations in valuing serious illness.

Section 4.2.2 considers alternative health definitions. Attention is given first to definitions that consider the dimen-

FIGURE 4-1. HEALTH DEFINITION: STEPS TOWARD QUANTIFICATION



sions of health in terms of various attributes which may be good and desired or alternatively may be bad and undesired. Definitions of varying broadness are examined. Attention is given second to definitions of health that focus in detail on symptoms or departures from good health, rather than desired attributes.

Section 4.2.3 considers the relevance to the measurment problem of causal factors affecting health. Attention to heredity* lifestyle and environment as causes of disease helps to arrive at judgments as to which health attributes should be emphasized. The view taken here is that definition and measurement should depend on the purpose at hand. In this study, the major purpose is to consider serious illnesses associated with environmental causes.

Section 4.2.4 turns to health measurement per se. Self-rating of health, the health risk appraisal approach and various approaches to measuring specific symptoms are considerd in detail.

Section 4.2.5 considers the implications of the preceding sections for empirical work on values associated with serious illness. A critique of approaches to health measurement from the point of view of their adequacy for the valuation of serious illness is given. Criteria include familiarity of respondents with symptoms, ability to encompass risk, adequacy in terms of the effects of serious illness on life cycle experiences, brevity and simplicity. Refinements and extensions to previous approaches to health measurement are suggested.

4.2.2. Alternative Health Definitions

Health is a key determinant of the quality of life. Central to the valuation of health is an understanding of the nature of health and the forces that influence it. Essential to this effort is the definition of human health such that deviations from the conditions it describes can be quantitatively described. While most people have an instinctive comprehension of what constitutes "health," few explicit working definitions are in common use. A multitude of biological, behavioral, cultural and social factors combine to shape human health--factors which act in both favorable and unfavorable ways to determine the level of well-being of a person at any point in time. "Death" is easily and explicitly defined as the end or extinction of'life. "Morbid" indicates diseased, sick, or unhealthy. But the definition of health itself is much more elusive, particularly when quantification is desired. Webster defines health as "physical and mental well-being," "soundness," and as "vitality," "prosperity," and "flourishing condition." Health is thought of also as simply the absence of illness or morbidity, i.e., a biological state dependent upon biological factors. As Banta (1981) points out, other more recent definitions of health also stress life functioning, mental state and self fulfillment. Hoyman (1965) explains that "health is a process of continous change or adaptationthroughout the human life cycle. In fact there is no single definition of health, although many definitions have been developed and are currently in use."

Carroll, Miller and Nash (1976) push the definition beyond absence of disease or discomfort to the ability "...to function effectively, happily, and as long as possible in a particular environment." A statement issued by the World Health Organization describes health as a "state of complete physical, mental and social well-being, and not merely an absence of disease" though this may be a statement of goals rather than a definition (Hanlon and Pickett, 1984). Great Britain's Royal Commission on the National Health Service aptly summed up the debate by declaring that "health itself is not a simple concept." Clearly, health is much more than mere absence of disease, and it has extremely great value.

Another related concept which is undergoing a change in meaning is that of "medical care," which traditionally has meant the provision of medical services by, or under the direction of, physicians. In recent years, the emphasis of such care has broadened to include preventive, as well as strictly curative, measures to preventive actions -- albeit still provided by the physician in a clinical setting.

Broader still is the term "health care," no longer the exclusive, province of the clinical physician. The term "health care" has come to replace "medical care" in many instances. Other new terms such as "health promotion," "health maintenance," and "disease prevention" have come into use (often interchangeably) to characterize the new preventive focus of health care which includes measures to be undertaken by individuals themselves. The Surgeon General's Report (1979) describes disease prevention as the protection of people from the harmful effects of health threats (diseases, environmental hazards). Health promotion measures are aimed, at well, as well as ill, people (promotion of activities to improve lifestyles).

Perhaps the most far-reaching of the new health concepts are "wellness" and "high-level wellness" (Ardell, 1977; Travis, 1977), which can be defined as "active processes through which the individual becomes aware of and makes choices toward a more successsful existence" (Hettler, 1981). Indeed, individuals are becoming increasingly aware of the merits of promoting their own health; sizable investments in time and other resources are being made.

Given the array of similar terms and definitions introduced above, an attempt to visualize these conceptual relationships suggests a health continuum described by Brubaker (1983). From this point of view, illness and death lie atone end, wellness at the other, while an individual's state of health is characterized by any degree of illness or wellness. Hettler offers a somewhat exapanded representation of the health continuum, adding terms to describe social well-being and ability to function within a society.

4.2.3. Role of Causal Factors

4.2.3.1 Background

Causal factors in health include hereditary, lifestyle and envionrmental factors. The causal factors are relevant to the definition and measurement of health, primarily because they determine the strength of various health attributes, which helps to distinguish the important from the unimportant. For example, if environmental change affects the incidence of cancer, then cancer symptoms and not the entire range of health attributes will be a principal focus in a study related to the environment. Among cancer symptoms, the degree of refinement of measurement of physical pain versus mental anguish will be determined by the relative strength of these attributes among cancer victims. Furthermore the causal factors determine how greatly a policy will affect health attributes, which in turn determines the range of change in health attributes that need to be studied.

As noted, health is influenced by a great number of forces, which can be described as hereditary, lifestyle, and environmental. Health can be seen as a process of continuous adaptation to the effects of these forces (Carroll, Miller, and Nash,). The nature of these influences and their relative importance to human health have been described by Hettler and by Blum . Health is described as an indivisible whole comprised of somatic (physical), social, and psychic (mental) well-being: illness in any one of the three facets affects the other two.

Of primary concern to the valuation of risk reduction are the environmental and- behavioral influences on health, and, to a limited extent, medical or health care. Heredity, though important, will not be given further attention here. Furthermore, the definition of environment outlined by Blum encompasses education, culture, and politics, factors beyond the scope of this study. For our purposes, environment consists of the interaction between human health and physical factors, such as air and water quality stressors, toxic substances present in the ambient environment, workplace hazards, radiation exposure and accidents. We assume that these aspects of the physical environment are partly under the control of an individual. Behavioral factors are under even greater control of the individual, and demonstrably influence personal health (Somers, 1980).

Some generally accepted conclusions are:

1. Everyone is endowed with certain health assets at birth. These may be above or below averages for the population in general. Regardless of initial birth endowment, however, the health of an individual is subject to change.

2. Interventions can influence the health of each individual either positively or negatively. Some interventions will have an immediate effect on health level (e.g., an automobile accident); the effects of other interventions may not manifest themselves until years after the intervention (latent effects of cigarette smoking, for example). These examples are illustrated in figure 4-2.

3. Health changes can be temporary and reversible, such as those associated with a common cold or exercise, or the health change can be permanent such as loss of a limb or contraction of emphysema.

4. Interventions may be voluntary, involuntary, or something in between. Cigarette smoking clearly is voluntary, but subjecting oneself to the risks of living near a hazardous chemical facility may be either voluntary or involuntary, depending on the amount of information available to the risk taker.

5. The health path will, at some point, terminate in death. For an individual, this termination can occur at any age, regardless of health.

4.2.3.2. Role of Behavior or Lifestyle

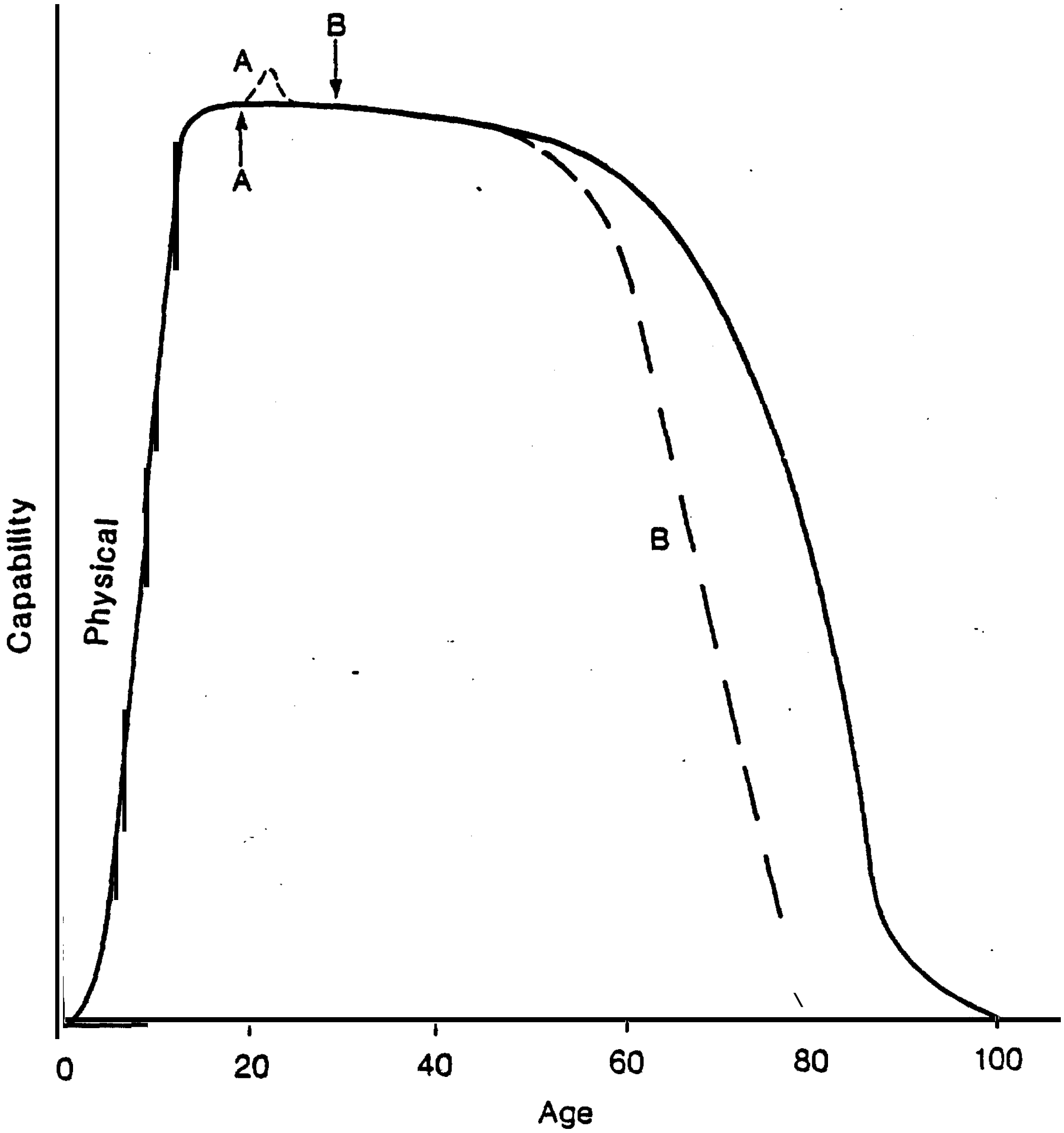
The influence that behavior can have on health has been long recognized, but systematic study and measurement of the implications of human actions on health are recent developments. Behavior patterns, or lifestyles, are at least partly under individual control. Lifestyle is intimately tied to social class and culture -- complex concepts describing characteristics of human interactions whose effect on health is not easily quantified. Nonetheless, it is clear that intervention against lifestyle-induced risk factors can reduce the probability of dying from the major causes of death (Berkman and Breslow, 1983; Klein, 1980; Mausner and Shira, 1984; Somers, 1980).

As Somers affirms, the links between behavior and health can be summarized in three statements:

1. The major causes of death, serious illness, and disability in the United States today are chronic disease and violence (see table 4-l):

2. Most chronic disease, disabilities, and premature deaths are related to a variety of environmental and

FIGURE 4-2. EFFECTS OF INTERVENTION



(A) is a short - term intervention which has an immediate short-term positive temporary effect on health (such as exercise).

(B) is another short-term intervention, but it has a latent but substantial permanent deleterious effect (such as exposure to a carcinogen).

TABLE 4-1. DEATH RATES: Leading Causes of Death, United States, 1979*

Cause	Rate/100,000 Population	Percent of All Deaths
Diseases of heart	333	38
Malignant neoplasma	183	21
Cerebrovascular disease	77	9
Miscellaneous chronic diseases**	56	7
Accidents, including motor vehicle, suicide, and homicide	70	8
Other	151	17
All causes	870	100

* Figures Rounded

** Diabetes, cirrhosis of liver, arteriosclerosis, bronchitis, emphysema and asthma, nephritis and nephrosis, peptic ulcer

From National Center for Health Statistics: General Mortality Statistics, 1979, Volume II, Part A.

behavioral factors,, which may be preventable;

3. Lifestyle pattern is the major behavioral risk factor **involved** in chronic disease contraction and disability (Somers).

No matter how comprehensive a nation's programs of enviornmental monitoring, or how extensive its health care services, the individual is ultimately responsible for minimizing threats to his health (Mechanic and Cleary, 1980). Factors such as smoking, alcohol and drug abuse, lack of exercise, reckless driving and failure to use seat belts can have considerable effects on health status and life expectancy (Breslow, 1978; Breslow and **Enstrom**, 1980; Mechanic and Cleary, 1980). This is not to say that people can easily correct negative behavior, because they are a part of the larger society and influenced by its institutions, which offer ambiguous messages about what is advisable behavior (Blum,; Surgeon General's Report,). Nonetheless, a willing individual can take steps which will measurably affect health status.

4.2.3.3. Role of Environment

Nature of Cause-Effect Relationships

Several approaches that relate environmental stressors'to health effects have been considered. While the present research is concerned with valuing health consequences, and not with environmental cause-effect relations as such, some attention to cause-effect relations is needed.

In the following sections, the source-receptor-effects system is described. Inventories of some of the pollutants receiving considerable study and public attention during the past 15 years are presented. The extreme uncertainty of cause-effect relationships is indicated. The relationship between the present section and section 3.2 on cause relations may be noted. Section 3.2 contributes to the study of light symptoms. It is more quantitative and has greater depth on a narrower range of pollutants than the present section. The present section serves as an introduction to a wider range of pollutants needed for the study of serious illness.

With few exceptions, the existence of causal relationships between pollution in the ambient environment and disease is difficult to quantify. Problems arise in attempting to relate exposure to a suspected agent with the development of illness, particularly if the illness is preceded by a long latency period (Task Force, 1982).

Figure 4-3 summarizes the complex path between a source of pollution and a variety of possible health effects including death. Moving down the diagram, the source of pollution may be industrial, residential, natural, etc. The emission may be from air, water, land, or a combination of media. The pollutants are likely to be diluted, transformed, and partially decayed before reaching exposed human receptors.

Note that defensive measures may be applied at the source to reduce the amount of, or entirely eliminate, the emission; other personal defensive measures may be applied prior to exposure (migration, air conditioning, etc.).

After or during continuous exposure it is likely there will be a finite latency period before adverse health effects, if any, appear. Uncertain and often lengthy latency periods make exposure-effect determinations very difficult.

The adverse effects, by definition, include any departure from optimal health. They range from almost imperceptible discomfort to terminal lung cancer. These adverse effects might be defined either as groupings of symptoms or as a clearly identified disease. Defensive and/or curative measures may reduce the effect of disease, but the adverse environmental effects may still be present. Adverse effects are not discretely divided into morbidity and mortality, but rather, the effects are seen to influence a health continuum which begins with optimal health (that existing in the absence of pollution) and ending with death.

Even prior to exposure, however, health can be adversely influenced by factors other than pollution, such as age and previous medical history. Each person exposed, at a different point on a different route, will die. The ch-allenge is to define the environmental influence on each path of mortality.

There is uncertainty at each linkage. Rosen (1981) concludes, "The most pressing need is for better estimates of risk valuations. That 'pressing need' would require much better data than currently are available."

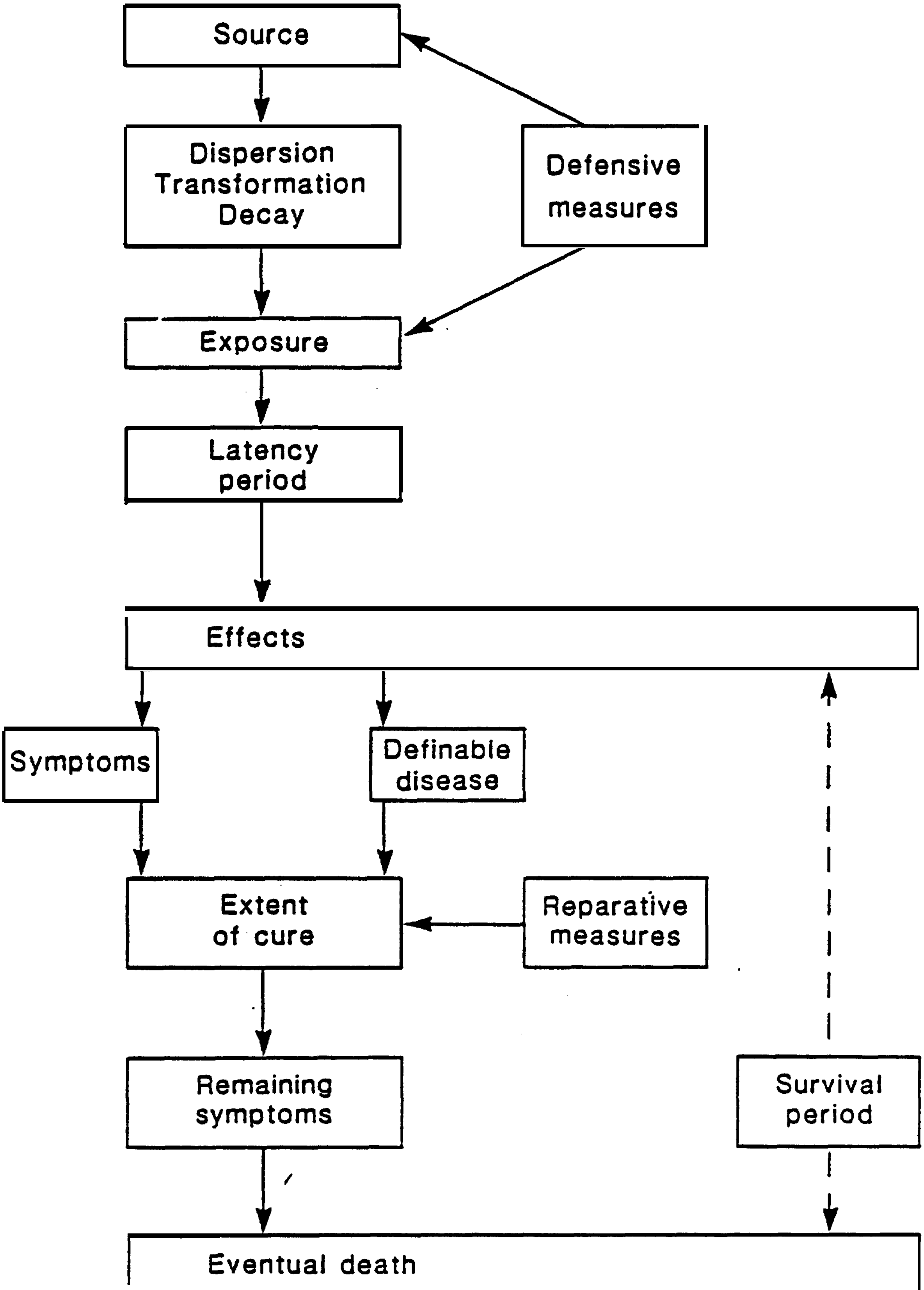
In summary, the complexities involved in establishing direct cause-effect relationships include:

Exposure to a toxic substance which may occur through direct contact with contaminated soil, water, air, food, or in the workplace;

The substance may be absorbed through the skin, ingested, inhaled;

Contact may be brief, prolonged, on single, multiple or continuous occasions;

FIGURE 4-3. POLLUTION-HEALTH RELATIONSHIP



The effects may be manifest very shortly after exposure or, as in the case of carcinogens, many years later;

The substance may act synergistically with other agents to produce illness, such as asbestos exposure combined with cigarette smoke;

The existing health status of the exposed person may affect the development of illness.

Of the harzards to human health arising from toxic substances, cancer is the target of most concern. It is the only major cause of death that has continued to rise since 1900, and is responsible for the loss of 400,000 lives each year. Some of the increase in cancer mortality since 1900 is a function of the greater average age of the population and the medical progress made against infectious diseases. But even after correcting for age, both mortality rates and incidence of cancer are increasing.

It is extremely difficult to assess the role that environmental factors play in causing human cancer because people are exposed to multiple stressors of both physical and chemical natures, some of which are related to their own behavior. Some early estimates of the proportion of cancers directly attributable to environmental agents were as high as 85-90 percent, but more recent analyses suggest that the role of environmental health pollutants is minimal (Task Force, 1982). This finding is supported by Doll and Peto (1981) who compare environmental and behavioral risks and conclude that the environmental and occuptional risks are relatively minor.

Much of what is known about the acute and chronic health effects of chemical substances has come from studies of workplace exposure. Many workers die each year as a resultofphysical and chemical hazards at work, but the exact magnitude of the long-term health effects of occupational conditions is unknown (Toxic Substances Strategy Committee, 1980).

Complex human epidemiology over a lifetime seems essential if progress at unravelling the cause-effect complexities is to be made. Animal studies are a poor substitute for human study because of the low ambient concentrations of toxics and long latency periods. In addition, animal studies cannot be used for annoyance symptoms (e.g., cough, headache).

The kinds of research needed to define environmental health risks are described in-depth in a report for U.S. EPA (Babcock and Allen, 1982).

Health Effects of Selected Environmental Contaminants

The following is a list of some of the most persistent and widespread pollutants which are of continuing concern to public health. The list resulted, from a review of (1) the first thirteen annual "status" reports of the Council on Environmental Quality, which examine the environmental issues of greatest concern to the government and public, (2) recent summary reports and literature of governmental agencies and other researchers in the field of environmental health, and (3) current toxicology references. (See Council on Environmental Quality, 1970-82; Duffus,1978; First Report on Carcinogens, 1980; Hamilton and Hardy's Industrial Toxicology, 1983; Handbook of Hazardous Materials, Fire-Safety- Health, 1983; Patty's Industrial Hygiene and Toxicology, 1978; Toxic Substance Strategy Committee, 1980; Waldbott, 1978). The inventory includes some substances which are ubiquitous in environment, but the health effects of which are uncertain, particularly with regard to long-term, low-level exposures. It must be stressed that the health effects listed below are associated primarily with chronic or acute exposure levels found in the workplace, and usually not in the ambient environment.

Asbestos is the generic name for several varieties of naturally occurring fibrous minerals which are heat, friction, and acid resistant, and are flexible and strong. They are used primarily in cement, fire-proofing, in formation of pipes and ducts for air, water and chemicals, brake pads and linings, roofing, garden ornaments, and furniture. Exposure can lead to pulmonary fibrosis (asbestosis), cancer of the lung, and the chest or abdominal cavity, and gastrointestinal carcinoma. Symptoms of respiratory illness include unexplained breathlessness upon exertion, cough, tightness of the chest, skin discoloration, enlargement of fingertips.

Arsenic is released in the combustion of coal, the manufacture of insecticides, herbicides and fungicides. It is present in the ores of copper and iron, and is oxidized during smelting. It is inhaled, ingested, and absorbed through the skin. It has been associated with cancers of the skin, lungs, and liver, as well as birth defects, nausea, diarrhea, stomach pain and constipation.

Benzene is the basic chemical of the group called aromatic hydrocarbons. It is used in the fabrication of paints, adhesives, dyes, plastics, chemicals, detergents, and pesticides, as an additive to gasoline, and in synthetic rubber manufacture. Benezene accumulates in the bones and fatty tissue of humans, and is a cause of leukemia, blood cell deformations, and is a depressant to the central nervous system. Drowsiness, headache, vertigo and nausea are associated symptoms.

Beryllium is a' metal that is resistant to heat, mechanical stress. It is both light and hard, has high conductivity, and is non-magnetic. It is used in a variety of industrial processes, aircraft engines, electric heaters, copper products, steel, cobalt, and nuclear power production. It has been associated with bronchitis, bronchiolitis, berylliosis, fibrosis, heart damage, pulmonary edema, and death. Symptoms include irritation of the upper respiratory tract, fever, chills, cough, sputum, shortness of breath, and weight loss.

Cadmium is a soft, ductile metal resistant to corrosion, and is used inelectroplating, manufacture of polyvinyl chloride, jewelry, soldering, batteries, aircraft engines, and automobiles. It is a contaminant of the soil, air, water and food. Symptoms include vomiting, diarrhea, colitis, hypertension preceding heart disease, chromosomal abnormalties, and death.

Motor-vehicle emissions are the largest source of carbon monoxide. Cigarette smokers experience extremely high'levels during smoking periods. Regardless of source, the exposures usually are temporary, with temporary displacement of oxygen in the blood stream as the primary health effect. Symptoms include headache, dizziness, nausea, impaired judgment, fatigue, and unconsciousness. Effects appear to reverse quickly at levels found in the ambient environment.

DDT is one of the group of persistent chlorinated hydrocarbon insecticides. It accumulates in the tissues of aquatic organisms, birds and other animals and plants which are part of the human food chain. It is present in soil, water, air, and food supplies. The long-term health effects of DDT on humans are uncertain, although it acts as a potent neurotoxin on insects and other animals. It is fat-soluble, and accumulates in the fatty tissue of humans, degrading very slowly over many years.

Dioxin, or 2,3,7,8 tetrachlorodibenzo-p-dioxide (TCDD), is a by-product which appears during the manufacture of herbicides. Again, its low-dose long-term effects on humans have not been established, but it is known to cause birth defects, miscarriages, fetal death and other reproductive disorders in animals. Agent Orange, the defoliant used extensively during the Vietnam War, contained TCDD. Chloracne is a skin condition resulting from acute exposure which is characterized by swollen eyelids, fingertips, and mucous membranes of the eyes and mouth.

Sources of ionizing radiation are both natural (sun, soil), and human induced (nuclear energy, weapons, isotopes from medicine and research). Exposure can result from internal or external sources, and through inhalation or ingestion. The various radionuclides can cause genetic mutation, chromosomal damage, impaired cell division, leukemia, cancers of the skin, lung, bones and genitals, cataracts, shortened life span, and death. Symptoms of radiation poisoning include loss of hair, skin ulcers, diarrhea, purpura, and skin hemorrhages.

Lead is an ubiquitous metal found formerly in paints and currently in batteries, gasoline, insecticides, pottery glaze, metal cans, and numerous industrial commercial products. It is found in the air, water, soil, and food. Lead contamination can lead to kidney disease, jaundice, gout, neurological disorders, convulsions, brain damage, sterility, premature birth of children, and death. Symptoms range from fatigue, weakness, headaches, and restlessness, to stomach and abdominal pain, lethargy, sleeplessness, vomiting, diarrhea, and hallucinations.

Mercury is found in medicine, dental fillings, fungicides, paint and paper manufacture, diapers, coal combustion, asphalt production, municipal incineration, electrical apparatus, and plastics. Health effects include visual impairment, brain damage, and fetal poisoning; symptoms such as tremors, skin eruptions, abdominal and muscle pains, and visual disturbances occur.

The principal anthropogenic sources of nitrogen dioxide are the combustion of coal, oil, natural gas, and motor vehicle fuel. Exposure can cause lung irritation, increased susceptibility to respfratory infections, pulmonary edema and death in extreme cases.

Organochlorine compounds (other than DDT) include aldrin, dieldrin, chlordane, and heptachlor, and have been used for many years in agriculture and malaria control programs. They are persistent in the environment, are biomagnified in the food chain, and are mutagenic and toxic to animal, life. The acute effects include liver damage and convulsions, with manifestations similar to those of DDT. The long-term effects of low-level exposures are not well known.

Ozone is an important constituent of photochemical smog, resulting from the reaction of nitrogen oxides and hydrocarbons in the presence of sunlight. It acts as an irritant to the mucous membranes of respiratory organs, and aggravates existing respiratory illness. Other effects include eye irriatation, impairment of cardiopulmonary function, and headaches.

PCBs (polychlorinated biphenyls) are chemical compounds which are nonflammable and highly plasticizing. They are used as heat transfer fluids and insulators, and in paints, adhesives, sealants, brake linings, flourescent lamps, electrical transformers, and capacitors. Like DDT, **PCBs** accumulate in fatty tissue and are slow to degrade: consequently, the long-term effects on humans are uncertain. The acute health effects include chloracne. Other symptoms include loss of hair and sexual power, headaches, numbness, abdominal pain and vomiting, deformed nails, joints and bones.

Soot, tar, and oil are the products of coal mining and combustion, and of the asphalt, tar and pitch industries. They usually contain polycyclic hydrocarbons and are associated with cancers of the lung, larynx, skin, scrotum, and bladder.

Anthropogenic sulfur dioxide is almost entirely a'result of combustion of coal, wood, and petroleum products. In the atmosphere, this pollutant can cause bronchial constriction, irritation of. the upper respiratory tract, eyes and ears, tightness in the chest, and can aggravate existing bronchial conditions. Damage to other environmental systems (acid deposition) may be the primary adverse impact.

Vinyl chloride is the main constituent of polyvinyl chloride, which is used in a variety of plastic products such as pipes, ducts, floor tiles, toys, waterproof upholstery, wrapping paper, film, records, boots, and sporting goods. Exposure to the gas can lead to liver cancer, acre-oteolysis, pulmonary teratogenic, mutagenic and chromosomal effects.

4.2.4. Health Measurement

4.2.4.1. Measurements in Terms of Ill Health

Levels of morbidity are commonly classified as a series of five "D's": disability, discomfort, discontent, disease, and death. Available evidence argues that trace environmental pollutants have their greatest impact on the first four "D's," although they may contribute to premature death as well.

Nationwide surveys of Americans provide information on prevalence of diseases and various health indicators. For example, the National Health and Nutrition Examination Survey (NHANES) clinically examines 20,000 different people every four years. A variety of health, nutritional, and disease prevalence information is obtained.

The National Health Information Survey (NHIS) provides data concerning the prevalence of disease. NHIS surveys more than 100,000 people per year, but the survey is restricted to question-answer interviews rather than examinations. These tabulations don't specifically indicate numbers of people who suffer from more than one malady or from the same malady more than once in a year. Likewise, there is no information about numbers of people who escape all the diseases. These surveys are cross sectional; they do not follow individuals through life. However, such information is useful for construction of likely scenarios which exhibit certain diseases during a lifetime.

In practice, many health status measurements are based on functional classification or therapeutic considerations involving diseased or disabled persons, not those who are well. That is, the definition is in terms of ill health, notgoodhealth.

Mausner and Kramer (1984) point out that "the development of disease is an irregularly evolving process, and the point at which a person should be labeled 'diseased' rather than 'not diseased* may be arbitrary." Left untreated, a disease may extend over time with symptoms changing in stages. This pattern may be termed its "natural history' or "clinical course." In relation to age, "...factors favoring the development of chronic disease are often present early in life, antedating the appearance of clinical disease by many years." The Mausner and Kramer framework for analysis of disease history follows.

<u>Stags of susceptibility</u>: Prior to the presence of a disease, factors which may increase the probability of its development may be present. These are termed risk factors. Age, sex, and race are examples which are not susceptible to human intervention, but alcohol or tobacco use can be subject to change. The presence of risk factors does not ensure disease development nor does their absence ensure freedom from disease.

<u>Pre-symptomatic stage</u>: Pathogenetic changes begin to occur, but the changes are not manifested in symptoms or signs which can be diagnosed.

<u>Clinical stags</u>: Recognizable signs and symptoms occur. It is at this point that classifications of health status based on functional or therapeutic considerations are made. Examples for categorization of cardiac disease appear below.

. Functional Classification:

Class I No limitation of physical activity because of discomfort;

Class II Slight limitation of physical activity; patient comfortable at rest but ordinary activity produces discomfort;

Class III Marked limitation of physical activity; comfortable at rest but less than ordinary activity causes discomfort;

Class IV Inability to carry out physical activity without discomfort.

Therapeutic Classification:

Class A Physical activity need not be restricted in any way;

Class B Ordinary physical activity need not be restricted, but patient is advised against severe efforts;

Class C Ordinary physical activity should be moderately restricted;

Class. D Ordinary physical activity should be markedly restricted;

Class E Complete bed rest advised; patient confined to bed or chair.

Descriptions of the natural history of the disease can be incorporated into indicated health effects. Lung cancer provides an example as follows:

1. The time when an individual is at no risk: either has not been exposed to the disease-causing agent (e.g., does not smoke or work with asbestos), or has been exposed the agent but is not vulnerable to it (e.g., even in the presence of smoke, newborn infants are not vulnerable to, and will not develop, lung cancer);

2. When one is vulnerable due to genetic propensities or a change in age or environment and therefore does not have an immune status;

3. When the damaging agent is present, at which time the exposed individual is in danger of acquiring the disease (e.g., anyone who smokes);

4. When an actual sign of disease is observable by a physician though not apparent to the victim (e.g., an abnormal chest x-ray);

5. When symptoms appear (severe coughing, chest pains, blood in sputum) and the individual, who knows that something is wrong, may tell a physician or other health worker; or

6. When disability, partial or complete, occurs.

The natural histories of many diseases are still unknown. In addition, some people never develop a disease despite the presence of a number of risk factors.

The listed functional classifications might be expanded into health indexes by defining various levels of minor discomfort and pain, and minor limitations of physical activity. Some health problems attributed to environmental interventions include learning impairment, peripheral neuropathy, and birth defects.

More simply, however, the history of the diseases provides descriptions of symptoms and consequences which could be quantified to a more or less exact degree depending on considerations of measurement feasibility in view of a particular study purpose.

4.2.4.2. Health Indexes

The health definitions discussed in Section 4.2.2 above suggested that a person has neither absolute health nor absolute illness (except death) but is in an ever-changing state and that one can be at any point on the continuum at any point in life (Murray and Zenthel, 1975). For some purposes it would be useful to quantify a health continuum, first numerically and then in terms of economic valuation of small increments of change. Initially efforts would focus on the simpler Brubaker health continuum, but the expansions by Hettler into risks and education might also possibly be useful in contingent valuation studies.

Howard (1984) defines morbidity as a fraction of death. This principle might be applied to a health index. Some of his methods involve trading years of life for improved health. He argues that there are no fates worse than death. Kane and Kane (1982) disagree.

Pulmonary function tests are used to measure lung capabilities (Babcock and Nagda, 1976). These and other physiological tests (exercise, work level, physical education performance, etc.) might provide another type of index.

4.2.4.3. Multi-Attribute Utility Functions

Researchers in the field of decision analysis have devised techniques for the characterization or prediction of health status (Katz et al., 1983; Wolinsky, et al., 1984), usually for the evaluation and comparison of health care treatment alternatives or medical policy decisions. Quantitative methods such as multiattribute utility functions (Keeney and Raiffa, 1976), or linear analog scales (Sutherland, Dunn and Boyd, 1983), are employed to evaluate the nature of trade-offs between quality of life and longevity (Pliskin, Shepard and Weinstein, 1980) or to measure a patient's preference for certain health states (Torrance, Boyle and Horwood, 1982). Such analytical methods may involve complex, lottery-based measurement techniques to determine probabilistic outcomes.

Boyle et al. (1982) employ a multiattribute health state classification system for use in a cost-effectiveness analysis of neonatal intensive care. Health status is defined by physical function, using measures of mobility and physical- activity; role function, or self-care, such as the ability to eat, dress or bathe with or without help; social-emotional function, measures of emotional well-being and social activity; and health problems, such as the presence or absence of a disability.

4.2.4.4. Self-rating of Health

As noted in Section 4.2.1, self-assessment is the most widely used measure of health status. The simple ranking of one's health (excellent, good, fair or poor) is crude in terms of being amenable to dollar quantification. However, the measure is simple, which makes it attractive especially for contingent valuation studies. While self-rating may not be useable for obtaining a value measure, it may be useable as a shifter in a function explaining health values, since the state of one's health is an influence onhowmuch one is willing to pay to avoid various specific symptoms or diseases.

4.2.4.5. Health Risk Appraisal

Health Risk Appraisal (HRA) is a tool for assessing the potential impact of individual behavior on the probability of dying from selected causes. In the course of an HRA, information about an individual's lifestyle and personal and family health history is elicited. This information is then compared with age, race and sex-specific mortality data and epidemiologic statistics to determine whether or not a person is a greater or less than average risk of dying from a selected cause, usually within the next ten years. Most HRAs are based on the work of Robbins and Hall and the statistical tables of Geller and Gesner (cited in Robbins and Hall). The objectives of the appraisal are to estimate individual risk with some degree of accuracy, and, by identifying risky behavior, help individuals modify or eliminate negative habits before the development of disease or disability (Dunton, 1981; Goetz, Duff and Bernstein, 1979; Hettler, 1981; Schultz, 1984).

The appraisal begins with a self-administered questionnaire. Each response is assigned a numerical "risk factor" which is then multiplied with the average risk of dying from each major cause of death. In the case of multiple risk factors for a single cause of death, a "composite risk factor" is calculated and then multiplied by average risk. The resulting disease-specific risk projections are then summed to form a "total projected risk." This is then compared to average risk to yield a new term "risk age" or "appraised age," i.e., the age of an average person with the same mortality risk as the respondent (Hettler).

This appraised age can be readily compared with actual age. If the total risk is greater than average (appraised age greater than the actual age), appropriate behavior modifications are suggested. If the suggestions are followed, the individual can hope to lower the overall risk projection, as expressed by the value of the "achievable age" (Hettler,). For example, a 34-year old may have the risk characteristics of a 30-year old (appraised age) but an achievable age of 29.

It is important to recognize that HRA instruments are, despite widespread use, still in an early stage of development. Concern has been expressed about the quality of the data elicited by a self-administered questionnaire and the accuracy of the risk (Fielding, 1981; Hettler, 1981, pp. 7-16; Sacks, Krushot, and Newman, 1980; Schoenbahh, Wagner and Karon, 1983.)

4.2.5. Implications for Valuing Serious Illness

The approaches to the definition and measurement of health that have been reviewed in this section serve to bring out the complex nature of this subject matter. The question becomes: How are we to measure health in the present study in view of the complexities?

A first implication that stands out is that measurement in terms of ill health is appropriate in view of the concern of the present study with values of eliminating undesirable environmental effects. As reviewed in Section 4.2.3, the possible diseases and symptoms caused by environmental pollutants can be described rather definitely in terms of ill health effects.

A second implication is that a broad definition of health effects is needed, extending beyond physical pain to mental well being and beyond this to the functioning of the individual. Conceptually one wants to value all the significant deleterious effects of the illnesses being studied.

Third, the fact that broad classes of illness are to be studied among many people in the population means that a basically simple approach must be followed. People must be able to think meaningfully about the measures, and it must be feasible to take the measurements and analyze them operationally as they pertain to large numbers of people. While the first and second implications go in the direction of detail and complexity, the third implication indicates that compromises with the first two implications will have to be struck.

If we look ahead to ensuing sections of this study, additional implications are obtainod. Thus a fourth implication is that the present state of health may affect values attached to contracting particular diseases. It is important to relate changes in health status to existing levels of health. A fifth implication is that a person's entire stream of life experiences with and without a disease affects hov the disease is valued. A person's age is particularly relevant, as is his expectation as to the course of events in his life without the disease. Sixth, one must look beyond health effects encountered with certainty to situations of uncertainty. Most people will never contract the diseases being considered. Environmental improvements will reduce the probability of contracting the disease. Health measurement must give attention, not only to certainty scenarios, but also to risk reduction in the context of uncertainty scenarios.

The first, second and third implications help in choosing between existing health measurement approaches. The third, fourth and fifth implications indicate needs for extensions and refinements of these approaches. Finally, the fact that the present study gives particular emphasis to devising contingent valuation approaches to serious illness affects choice of health measures.

One of the clearest conclusions from these implications is that measurement in terms of ill health effects is called for in the present study. In view of the need for operational simplicity, symptom descriptions in terms of average conditions brought about by a disease are the basic approach recommended here for studying values connected with serious illness. The symptom descriptions need to be supplemented by allowance for full effects of the symptoms on mental well being and functioning of individuals. In a contingent valuation approach, this can be done by making the respondent aware of a wide range of effects of the symptoms.

For getting at the effects of existing health levels on valuations, self rating of health has much to offer. It is more readily available than more sophisticated measures, and the need for precision is less great for measuring the existing health level than the specific effects of the disease being valued.

The health risk appraisal approach, which takes the trouble to relate highly specific individual characteristics, including age and lifestyle factors to health prospects, is highly congenial to the framework of the present study which stresses the importance of life experiences and alternative future life path scenarios. It plays a prominent role in some of the approaches to health valuation developed later in this study.

The multi-attribute utility function approach has much to recommenditconeptually for some purposes, but it is not used in this study, largely because it apears operationally too complex for this study. Respondents in contingent valuation experiments can and should be encouraged to take account of the multi-faceted nature of health effects in framing responses, which is consistent with multi-attribute utility functions. But to quantify the utility function as such is not attempted in this study, which is concerned with going directly to dollar valuations of the sum of all the effects of an illness.

The later parts of this study build on the choices among existing health measures implied by the above remarks. Refinements to the health measurement approaches are developed takfng account of individual circumstances in a life cycle context with certainty and uncertainty scenarios.

4.2.6 References

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4.3. THE QUANTITY AND QUALITY OF LIFE: CONCEPTUAL FRAMEWORK

4.3.1. Introduction

Serious professional interest in cost benefit analysis of projects involving safety, illness and death probabilities has its origins in environmental concerns beginning in the 1960s as a practical policy matter, and in the work of Schelling and Mishan as an intellectual one. These authors showed how to put the problem into the "willingness to pay" framework of applied welfare economics, which has been the guiding principle in economic research in this area ever since. Subsequent research has followed two distinct conceptual lines. Beginning with the important paper by Usher, one line has followed a strictly life cycle framework. Building on the paper by Yaarf, work by Cropper, Conley, Ehrlich and Chuma, and Arthur (this the only general equilibrium paper in the literature) have built increasingly elaborate models of life-cycle valuation criteria. Another line, and one which has tended to guide most empirical work, uses a simplified single period model without explicit regard for life cycle considerations (e.g., Jones-Lee, Rosen, Thaler and Rosen). The single period models are conceptually simpler than life cycle models, but may miss some important considerations that arise in the fully dynamic life-cycle setting which the problem obviously requires.

This section is concerned with life cycle models of safety and health evaluation. One of its goals, at least by implication, is to show the close relationship between life cycle and single period models. This is achieved by stripping away many of the detailed complexities of life cycle dynamics to reveal the internal structure of the problem most clearly and in the most elementary manner. In fact this is most easily done in a deterministic setting, in which a person has a fixed longevity and is allowed to optimize consumption and labor supply decisions over his fixed length of life. The solution to the optimal program naturally leads to a simple formula for putting dollar values on suitably small increments of longevity, using the principles of duality theory. Models of this type are discussed in the following two sections. First a simple consumption allocation problem is analyzed and the valuation equation exhibited. Then the model is complicated in a number of ways. It is shown that most of the principles underlying the simplest model carry through for all variations on the theme. This model may be extended to include valuation of morbidity as well as of longevity.

While deterministic models are useful in their great simplicity, they suffer obvious defects in terms of realism.

Therefore the remainder of the paper turns to stochastic models using actuarial calculus and the insured-consumption-loans device for dealing with intertemporal budget constraints introduced by Yaari. The insurance features of these schemes allow the analysis to separate allocation decisions regarding consumption and labor supply from uncertainty regarding length of life. The exposition brings out the intimate connection between deterministic and stochastic models and shows that the same types of parameters are relevant for both. Chief among these is a parameter which is naturally interpreted as reflecting the inherent substitution between "quantity" (or longevity) and "quality" of life. It is closely related to the economic concept of intertemporal substitution. Estimates of the "values of life" from existing empirical studies allow rough imputations of this parameter, which ultimately relate to the question of how much of the economy's wealth should be spent on safety, health and longevity concerns. Other relevant factors are shown to include the rates of interest and time preference, the level of wealth and the person's stage in the lifecycle.

An interesting implication of this analysis is that personal valuations of life expectancy inevitably vary over the life cycle. This important point is the inevitable consequence of the finiteness of life itself and the effect of discounting. Hence a person who chooses an action when young that affects subsequent mortality may life to regret it-later, in the sense that in the circumstances he finds himself in later he would have somehow "preferred" not having taken the earlier action. However, there is nothing either inconsistent or irrational in this type of behavior, since by hypothesis, the full future consequences of current actions are foreseen when they are chosen. It does mean, however, that the benefit side of any cost-benefit calculation on these matters must take account of the life cycle structure of valuations and will be sensitive to the age and demographic composition of the population and how it changes over time.

4.3.2. The Value of Longevity: Deterministic Model

In this section we consider a deterministic problem which sets many of the essential ideas for the valuation of life expectancy. Consider a person with time-seperable preferences for consumption over a lifetime of length T:

(4-l). $$U = \int_0^T U(c(t))e^{-at}\,dt,$$

where the concave function u(c) evaluates the utility of consumption c at time t and a is a fixed and constant rate of time preference. The person is endowed with a fixed wealth W at the beginning of life and has a fixed investment opportunity which yields a return of r. The problem to be considered is how the person would allocate his fixed wealth over consumption at each point in the life cycle. The solution to this problem yields the valuation we seek.

Let W(t) represent remaining wealth at time t and let dW/dt be the change in wealth at time t. Then the budget constraintfacing this person may be written in flow terms as

$$dW/dt = rW - c, \tag{4-2}$$

which has a ready interpretation. rW is the income from investing current wealth at rate of return r and c is the amount that is consumed out of this income. If consumption falls short of current income the person's wealth must be increasing, while if current consumption exceeds current income his wealth must be decreasing.

The formulation of preferences in (4-l) is consistent with the situation of an unattached individual who has no heirs and therefore no bequest motive. We impose the condition that the person cannot die in debt, and since he does not wish to leave wealth (there are no heirs), we have a boundary condition for the differential equation in (4-2) that W(T) = 0. The person will obviously wish to consume all endowed wealth over the entire life cycle. Using this boundary condition and integrating (4-2) yields an equivalent budget constraint in terms of stocks:

(4-3) W = Integral from 0 to T $c(t)e^{-rt}$ dt

Initial wealth equals discounted lifetime consumption.

Consider the problem of maximizing U in (4-l) subject to constraint (4-3). Let V(T,W;r,a) denote the maximum of U given that the sequence c(t) is optimally chosen. Clearly V is a function of the parameters of the problem, which are T, W, r and a. This _value function_ allows us to calculate the value of longevity. Let L denote the value of longevity, defined as the maximum amount of wealth a person would willingly give up to extend his life by a small increment dT. In exchange for an increment dT, the person would be willing to pay as much wealth as would keep V at its initial level. This is therefore nothing more than the marginal rate of substitution between T and W implicit in V. Totally differentiating V and setting the result equal to zero, we have

(4-4) v = - dW/dT = partial of V w.r.t./

partial of V w.r.t. W

To evaluate this expression it is necessary to first solve the maximum problem.

Associating a Lagrange multiplier **m** with constraint **(4-3)**, first order conditions for maximization of (1) subject to (3) are

$$(4\text{-}5) \qquad u'(c)e^{-at} = me^{-rt} \qquad \text{for all } t.$$

The marginal utility of consumption is proportional to the positive multiplier **m**, suitably discounted by' the difference betweem r and a. To simplify even further, let us analyze the leading case where r = a. Then (4-5) implies u'(c) = **m**, which in turn implies c(t) = c, a constant for all t on **[0,T]**. That is, lifecycle consumption is "flat" and the same at all ages, an especially pure form of the permanent income hypothesis. Using this result and substituting into (4-l) defines V as **(since** r = **a)**.

(4-6) V = Integral from 0 to T u(c)e^{-rt} dt = u(c) integral from 0 to

= u(c) integral from 0 to T e^{-rt} dt = **u(c)(1/r)(1-e**$^{-rT}$)

= (by definition) **u(c)A(T),**

where A(T) = **(1/r)(1-e**$^{-rT}$**)** is simply the value of an **annunity** received for T periods at rate of interest r. A(T) is the "correction factor" for finite life.

Now from the budget constraint, after substituting c(t) = c, we have

$$(4\text{-}7) \qquad W = (c/r)(1-e^{-rT}) = cA(T) .$$

Therefore c = W/A, which is just the finite life-corrected level income which exhausts the endowment W at T exactly. Putting (4-6) and (4-7) together, we have

$$(4\text{-}8) \qquad V = u(W/A(T))A(T) .$$

There are two immediate consequences of (4-8). First, V is strictly increasing in W:

$$V_W = \text{partial of } V \text{ w.r.t. } W = u'(W/A) > 0;$$

greater wealth makes a person better off. Second, the effect of T is confined to its influence through A. Now A is increasing in T, since an annuitythat lasts longer has a larger value. But A has two effects on V. It has a negative effect through its influence on the first term in $u(.)$ in (4-8) but it also has a direct positive effect through the multiplicative second term in (4-8). Concavity of u(c) implies that the second direct effect dominates and that V is increasing in A:

(4-9) $$V_A = \text{partial of } V \text{ w.r.t } A$$

$$= -(W/A)u'(W/A) + u(W/A) = u(W/A)(1-E)$$

where $E = cu'(c)/u(c)$ is the elasticity of the function u(c). We require $0 \leq E \leq 1$ for the problem to be well conditioned and for the marginal condition (4-5) to characterize the optimum. Therefore $V_A > 0$. Though there is no direct value of length of lifetime T in preferences in this problem, its value is induced by its effect on A. From the definition of A(T), we have $A'(T) = e^{-rT} > 0$.

We are now prepared to evaluate v. Totally differentiating (4-8),

(4-10) $$dV = u(W/A)A\{(E)dW/W + (1-E)(A'/A)dT\}.$$

Setting (4-10) equal to zero, the value of longevity is

(4-11) $$v = -dW/dT = A'(T)[(1-E)/E](W/A) = e^{-rT}[(1-E)/E](W/A)$$

(4-11) displays some interesting properties:

(i) v is increasing in wealth (given E). Longer life is more valuable to wealthier persons and they are willing to pay more to extend it. This is one reason why life expectancy is longer in societies with greater wealth, which spend some of it on safety devices and living styles that promote longevity. Notice however, that in this formulation $-d\log W/dT$ is <u>independent</u> of W: all individuals are prepared to pay the same percentage of their wealth to extend life when preferences are of this form.

(ii) An especially interesting and unusual implication of (4-11) is the role of the term in E, which relates to the curvature properties of the function of u(c). This in turn is related to the question of intertemporal substitution possibilities in consumption. To see this most clearly, let us examine some limiting cases. First, look at what happens in the limit as E goes to unity, so that u(c) goes to a linear function of c. Then according to (4-1), we have that U is essentially summable in c(t) and all that matters to the person is total consumption over the life cycle, andnotatallhowa given total is distributed over ages. One big consumption bash at some time is equivalent to many periods of much smaller consumption levels, for example. Here we have VA = 0, so v goes to zero as well. A person is not willing to pay to extend life when E -1 because the increasedhorizonis completely offset by lower per period consumption: V = W in this case, which is independent of T. This is a case of perfect substitution between the "quantity" and "quality" of life, equivalent to perfect intertemporal substitution in consumption across periods.

At the opposite extreme, consider what happens when E goes to zero. Here the indifference curves in the c(t) hyperplane exhibit "elbows" and fixed proportions (in the E = 1 case they are straight lines), so intertemporal substitution possibilities are nil. Now the person is willing to pay large amounts for greater life expectancy, since each year of life becomes "essential." The main point is that limited substitution of consumption across years of life implies that quantity and quality of life are imperfect substitutes for each other. There is an inverse relation between the value of longevity and the degree of intertemporal substitution in consumption in lifecycle preferences.

(iii) Substituting for the definition of A(T) in (4-11) we have

$$v - e^{-rT} / (1-e^{-rT})[(1-E)/E]Wr,$$

and it follows that partial of v w.r.t. T C 0. Hence a person with a smaller horizon is prepared to pay more to extend life than a person with longer horizon. In particular, this result implies that other things equal, younger persons are willing to pay less to extend their life than older persons are prepared to pay. That L itself changes over the lifecycle may cause a person to, in some sense, regret past decisions. However, there is nothing inconsistent with this when preferences are time-separable and discount rates are constant over age.

(iv) v is not necessarily decreasing in r (given that a adjusts conformably). This experiment applies to a comparison of two societies, one in which persons are impatient and have high rates of time preferences, and one in which they have more foresight. In both, however, the interest rate adjusts to the rate of time preference. There are two effects: On the one hand the term in the exponentials in the expression under (iii) is decreased by an increase in r. On this account the value of longevity tends to fall. But on the other hand, the term in Wr is increased and real income is larger. The second effect dominates if T is short enough, but if T is sufficiently long then v will fall. It is surprising that the effect of a change in time preference and interest rates (together) cannot be signed.

Let us now examine the internal consistency of the solution. Suppose that the program derived above has proceeded for s periods. From that point on the person has $T' = T-s$ years of life of life left and has already consumed a fraction of initial endowed wealth. Let W' denote current wealth (after s periods have passed by). Then

$$W' = \text{integral from 0 to } T' \text{ of } (W/A)e^{-rt}\,dt = (W/A)B,$$

where $B = (1/r)(1-e^{-rT'})$ is the value of the remaining annuity for T' periods. Now it is clear that the optimal program from time $\underline{s}$ onward remains the same as before, because the budget constraint becomes, from point $\underline{s}$ onward, integral from 0 to T of $c(t)e\,dt = cB = (W/A)B$ and we have already determined c to be equal to W/A. Another way of saying this is that the new budget constraint becomes $W' = cB$, so $c = W/A$ also solves the "new problem" from $\underline{s}$ forward. The person doesn't change his plan. However, the value function changes as the person ages:

$$V' = \text{integral from 0 to } T' \text{ of } u(W/A)e^{-rt}\,dt = u(W/A)B$$

so the value V' when there are T-s periods left is smaller than the value V when there are T periods remaining because $B < A$. That the value function is decreasing with age (reaching its minimum at the age of death T) is due to the fact that terms are continually lopped off the sum of discounted utilities of further consumption as the person ages. Now in terms of remaining wealth, we have $c = W/A = W'/B$, so $V' = u(W'/B)B$ is precisely of the same form as (4-8) above, with B replacing A. Substituting from the above, we find

$$v' = ve^{rs},$$

so the value of life grows exponentially with age ($\underline{s}$) in this case.

The relationship between v' and v in the expression immediately above makes clear the economic rationale for increasing value of life with age. In this deterministic problem, the the experiment tacks on extra years at the end of the program, and these terms are necessarily discounted-to present value. Something might have very large value at the time it occurs (as it does, for example, for a person at death's door, so to speak. in this problem). However, if the event will only occur sometime in the future, its current value is greatly reduced by discounting. Even though a young person and an old person will have the same value of longevity when they actually reach age T, at their current ages, this is discounted by a different amount due to horizon differences.

This simple point has some important practical implications, and even survives to stochastic models where the length of life is random rather than deterministic. It means that risks and actions which have long latency periods and which are long deferred can have small value to many people, especially young people. The young may appear "reckless" on this account, but such "recklessness" is rational. To illustrate the point further, suppose there is an opportunity to extend life by dT which costs a fixed amount independent of age. Then, since L is increasing in age, there is a threshold age, call its* such that people who are younger than s^* do not purchase the opportunity, while those whose age exceeds s^* purchase it. Similarly, if the market provides an opportunity to trade money and wealth for shortened life expectancy (as in risky jobs, for example) there is another threshold age s^{**}, such that people who are younger than s^{**} voluntarily make the trade and undertake the risk, whereas those who are older than s^{**} do not do so.

4.3.3. Extensions of Deterministic Model

4.3.3.1. Nonconstant Consumption

The strong result that $c(t) = c$ in the model above derives from the assumption that $r = a$. It is well known that when these two parameters are unequal then c(t) is either decreasing or increasing. To illustrate, consider an example in which r exceeds a. Then application of (4-5) shows that c(t) is increasing. To make further progress we need to be more specific about u(c), so assume the constant elasticity case where $u(c) = c^E$, with $0 < E < 1$. Detailed analysis reveals that the relevant discount factor in this case is $q = (a - Er)/(1-E)$. Defining $A^* = (1/q)(1-e^{-qT})$ we obtain the following expressions for V.

In the case where $q = 0$, V becomes

$$V = W^E T^{1-E}.$$

In this case there is direct valuation on T itself, because the effective discount rate is zero (and only sums matter, not discounted sums). Here we find

$$v = [(1-E/E](W/T),$$

which is increasing in W and decreasing in E and T, much as before. In the more probable cases where q RO, we find

$$v = W^E \ (A+ \ ^E = (W/A^*)^E \ A^* = u(W/A^*)A^*,$$

which has a form very similar to the simpler case where $r = m$ in all cases therefore the conclusions are very similar to the analysis above and need not be repeated.

4.3.3.2. Age-Dependent Preferences and the Quality of Life

The model so far has assumed that the utility function u(c) is constant over life and has no age-dependent factors built into it. However, it is intuitively clear how the presence of such factors would affect the analysis. Suppose for example that the quality of life deteriorated with age, so the utility function u(c) is decreasing over time. Then the value function would be adjusted conformably and the value of life calculation would take this into account, e.g., if life got progressively worse with age then a person would not pay as much to extend it, obviously.

For example, introduce the age-dependent factor in a multiplicative way as follows:

$$U = \text{integral from 0 to T of } u(B(t))c(t))e^{-at}.$$

Here the term in $B(t)$ represents a consumption correction factor to make "real" consumption equivalent across ages. For example, if B(t) is decreasing in age, it takes an ever increasing amount of consumption to make up for the lower "efficiency" of consumption as a person ages. In this case the marginal condition, in (4-5) above is simply altered by multiplication of the left hand side by B(t). If we also assume that $B(t) = e^{-Bt}$ then the analysis is virtually identical to that of section) 4.3.3.1 (where the discount rate of time preference does not necessarily equal the rate of interest). Again, the refinement is a minor one.

4.3.3.3. Bequests

Suppose now that the person has heirs and that at the time of death all remaining wealth is transferred to these heirs. The standard way to incorporate a bequest motive into a life cycle problem is to introduce a bequest function into the utility function. Thus write

$$U = \text{integral from 0 to T of } u(c(t))e^{-at}\,dt + e^{-aT} f(Wb),$$

where the first term is identical to that above, and the second term reflects the person's utility of bequests. The amount of bequests are W_b which yield utility (discounted to present value) of $e^{-aT} f(W_b)$. Now the wealth constraint becomes

$$W = \text{integral from 0 to T of } c(t)e^{-rt} + W_b e^{-rT}$$

and the necessary conditions to the maximum problem are

$$u'(c)e^{-at} = m\, e^{-rt},$$

$$f'(W_b)e^{-aT} = m\, e^{-rT}.$$

Assuming $r = a$ again for simplicity, we have

$$u'(c) = f'(Wb) = m$$

and the constraint becomes

$$W = cA + Wb\, A'$$

where A and A' $= dA/dT$ were defined above.

Using these conditions and applying the envelope theorem to v, we find

partial of V w.r.t. W $= m$

partial of V w.r.t.

$$= [u(c) - m]e^{-rT} - re^{-rT} [f(Wb) - mW_b].$$

Using the simplified first order conditions and simplifying yields

$$v = -dW/dT = e^{-rT} [c(1-E)/E - rW_b (1-E^*)/E^*],$$

where $E^* = f'(W_b)W_b / f(W_b)$ is the elasticity of the bequest function. Thus the presence of bequests and bequest motives reduces the value of life in and of itself, because of the offsetting benefit to heirs of the person's demise. Of course this strong conclusion is built on some special assumptions, of which two are particularly important. One is that the utility of own consumption may itself be affected by the presence of heirs and children in the household. People tend to have children because they want to and because it increases their own utility over and above any affect of bequests. Hence the presence of heirs may make life itself worth more to the person, which tends to increase the value of longer life rather than to reduce it. Second, the. heirs may suffer a loss of utility from the person's death, and this utility loss should be valued by the person himself if he is altruistic (really, a form of reciprocal altruism). This factor would also tend to increase the value of longer life.

4.3.3.4. Labor Market Activities

Let us now consider a person who has endowed wealth W, as before, but who also has the opportunity to work at an hourly wage rate w. It is necessary to alter the utility function to handle this case because some valuation must be placed on leisure. Let L be leisure and normalize so that $0 \leq L \leq 1$. Then (1-L) is the amount of time devoted to work. Maintaining time seperable preferences as before, write the utility function as

(4-12) $U =$ integral from 0 to T of $u(c(t),L(t)e^{-at}$ dt,

where the utility function $u(c,L)$ has conventional properties. The person has two sources of income in this problem. One is endowed wealth and the other is (endogenously chosen) earnings w(l-L). .The intertemporal budget constraint equates the present discounted value of earnings plus endowed wealth to the present discounted value of consumption over the life cycle:

(4-13) $u =$ integral from 0 to T of $w(t)(1-L(t)e^{-rt})dt$

$=$ integral from 0 to T of $c(t)e^{-rt}$ dt.

Optimality conditions for choice of c(t) and L(t) which maximize (4-12) subject to (4-13) are

(4-14) $U_c(c,L)e^{-at} = me^{-rt}$,

$U_L(c,L)e^{-at} = mwe^{-rt}$.

Solving these two equations along with the budget constraint yields the optimal trajectories for L and c.

We can place this problem in the context above by making the simplifying assumption that $r = a$ and that $w(t) = w$. Then (4-14) implies

(4-15) $U_L(c,L)/U_c(c,L) = w$.

$$U_c\ (c,L) = m,$$

which imply that $c(t) = c$ and $L(t) = L$ are constants over the life cycle. Therefore, we may write

$$V = \max_{c,L}\ \{u(c,L)A + m\ (W + w(1-L)A - cA)\}, \tag{4-16}$$

where again A is the present value of an annuity that lasts for T periods. Using the envelope property of a maximum., we find

$$\begin{aligned} V_W &= m, \\ V_W &= m(1-L)A, \end{aligned} \tag{4-17}$$

$$\begin{aligned} V_T &= [u(c,L) + m(w(1-L) - c)]A', \\ &= [u(c,L) - m\ (W/A)]A', \end{aligned}$$

where the second equality in the last expression follows from the budget constraint.. Therefore

$$v = V_T/V_W = [u(c,L)/u_c\ (c,L) - (W/A)]A', \tag{4-18}$$

since $m = u_c$ from the marginal conditions, Defining the elasticity $E = cu_c\ /u$ as before, (4-18) becomes

$$v = [c/E - (W/A)]A'. \tag{4-19}$$

This may be written in yet another way: solving for c from the budget, we have $c = W/A + w(1-L)$. Substitute this into (4-18) and rearrange:

$$v = [(W/A)(1-E) + w(1-L)]\ e^{-rt}/E\ . \tag{4-20}$$

Look at (4-19) first. The value of longevity has both a posit'ive and negative term (of course suitably discounted-- $A' = e^{-rT}$). The positive term is the level of consumption adjusted by the inverse of E, and since E cannot exceed unity. the actual value of consumption is a lower bound for this term The negative term in W/A, which is just the level income available from an endowment of nonhuman wealth W available at interest rate r from T periods. This must be subtracted from the adjusted consumption level because an increment of life T lowers the annuity value of income available from W because it must be spread over a longer interval and consumption in earlier periods is lowered on that account.

The second form of v in (4-20) shows that the value of longevity has a relationship with observed income as well as with observed consumption. The first term in this expression is $(W/A)(1-E)e^{-rt}/E$, precisely the same as when leisure is not considered in the problem. To this we need to add the extra income available from work when the person lives longer. However, it is not the extra earnings alone that must be added, but that amount divided by E. That is, observed earnings is a lower bound to the extra adjustment and is only an unbiased estimate when E is very close to unity. Again, this adjustment reflects imperfect substitution between quantity and quality of life when consumption and leisure are not perfect substitutes intertemporally.

4.3.3.5. Retirement

The model in section 4.2.3.4 assumed that the person worked over his whole life, and would be relevant for a situation of "early" death. However, for most people work patterns over the life cycle follows a systematic course of full time work up to a certain age followed by a full time retirement. The model above may be extended to cover this case most easily be assuming that the wage w is available up to some retirment age, say T^*, at which time w drops to zero and the person consumes full time leisure. 'The the utility function must be written

u = integral from 0 to T* of $u(c_1(t),L(t))e^{-at}$ dt

+ integral from T* to T of $u(c_2(t),1)e^{-at}$ dt,

where c_1 denotes consumption during the years in which a person works and c_2 denotes consumption when the person is retired and leisure is fully consumed ($L = 1$). The budget constraint is conformably altered to

w + integral from 0 to T* of $w(t)(1-L(t))e^{-rt}$ dt

= integral from T* to T of $c_1(t)e^{-rt}$ dt

+ integral from T* to T of $c_2(t)e^{-rt}$ dt

and the optimal program chooses L(t), $c_1(t)$ and $c_2(t)$ to maximize U subject to the budget constraint as before. Omitting details and making the same simplifying assumptions as above yields an expression for v of the form

$$v = c_2\ [(1-\hat{a})\hat{a}]A',$$

which looks very much like the first problem considered here. There are two minor differences. First, the relevant consumption level is that applicable to retirement rather than to pre-retirement. The second is that the adjustment factor--the elasticity term $\hat{\epsilon}$ is calculated at the retirement utility level of leisure where L = 1: $\hat{a} = c_2 u_c(c_2,1)/u(c_2,1)$. It is not at all obvious whether or not $\hat{a}$ falls short of or- exceeds the corresponding elasticity calculated at the preretirement optimum utility: this would depend on the precise form of preferences. Nor is it entirely obvious, without more structure on preferences, whether c_2 exceeds or falls short of c_1. This would depend on the nature of complementarities and substitution between consumption and leisure, about which little can be said in general. However, the budget constraint does imply

$$c_2 = [(W/A^*) + w(1-L) - c_1] / (A - A^*)/A^*,$$

where A* is the annuity formula for T* periods and A is the formula for T periods. It is clearthatthe longer the period of retirement, the smaller is c_2 and the lower the value of v, ceteris paribus. It is also clear that v is larger for people with greater nonhuman and human wealth, because retirement consumption will be larger in these cases.

4.3.4. The Value Of Morbidity

The ideas in the last two extensions provide a basis for beginning to evaluate morbidity. Imagine the following situation: The person is ill for exactly S periods, after which time he becomes "whole." During the period of illness, utility is $G(c_1,L_1)$, while during the normal (well) period utility is $u(c_2,L_2)$ as before. Here the subscript 1 refers to these variables in the well-state. For the demarcation of illness to make any sense, we must have that $G(c,L) < u(c,L)$ when both functions are evaluated at the same arguments. Then illness makes the person worse off. In addition, a person who is ill cannot work on the same terms as one who is well. Represent this by a drop in the wage: if the wage in state 2 is w, then the wage in state 1 is aw, where a < 1. In addition, medical and other expenses may be required if the person is ill. Denote these, as a flow, by D.

The budget constraint for this problem is

(4-21) W + integral from 0 to S of $aw(1-L_1(t))e^{-rt}$ dt

+ integral from S to T of $w(1-L_2(t))e^{-rt}$ dt

= integral from 0 to S of $(c_1(t)+D)e^{-rt}$ dt

+ integral from S to T of / $c_2(t)e^{-rt}$ dt .

Of course it may turn out that the person chooses not to work in state 1, in which case the first earnings expression in (4-21) is zero. Again, maintaining seperability for analytical convenience, lifetime utility is

$$(4\text{-}22)\quad U = \text{integral from 0 to S of } G(c_1(t),L_1(t))e^{-at}dt$$

$$+ \text{ integral from S to T of } u(c_2(t),L_2(t))e^{-at}\,dt.$$

If we assume that r = a and that w is independent of t, we again find that the c's and L's are constant in the optimum program, so that

$$(4\text{-}23)\quad V = \max\{G(c_1,L_1)A_S + u(c_2,L_2)(A_T-A_S)$$

$$+ m\,[W+(aw(1-L_1) - cl - D)A_s$$

$$+ (w(1-L_2) - c_2)(A_T - A_S)]\},$$

where A_t is the annunity formula for t periods. We are interested in how much wealth a person would be prepared to pay to reduce the period of illness by an increment dS. This again is a marginal rate of substitution calculation comparable to the definition of v. Hence define M as the corresponding value of morbidity:

$$(4\text{-}24)\qquad M = (dW/dS) = V_S/V_W.$$

From (4-23) and the envelope theorem'it follows that

$$V_S = (G - u)A_S + [y_1 - y_2 - (c_1 + D - c_2)]A'_S,$$

$$V_W = m,$$

where $y_1 = aw(1-L_1)$ and $y_2 = w(1-L_2)$ are earnings in states 1 and 2 respectively. Applying the definition (4-24),

$$(4\text{-}25)\quad M = \{[u(c_2,L_2) - G(c_1,L_1)]/m + (y_2 - y_1) + c_1 + D - c_2)\}A'_S.$$

This expression shows that the value of morbidity reduction is composed of three distinct parts. One part is the difference in earnings between the two states, or “foregone earnings" commonly found in practical work. To this must be added the cost of medical care and related expenses (D), which is also commonly incorporated in empirical measures. However, these measures usually excluded two other components which are more difficult to measure. The first of these is the dollar value of the utility loss of illness, reflected in the first bracketed term in the expression for M- -division by the marginal utility of wealth converts the utility difference to an equivalent dollar magnitude. This term would be related to the concept of "pain and suffering" associated with personal injury litigation. Its magnitude obviously varies with the degree of debilitation, and also with the extent to which the relative marginal utilities of consumption and leisure are affected by the illness and the extent to which "leisure" and consumption in the ill state are complements or substitutes. Little can be said about this in general, and it must be analyzed on a case-by-case basis. The third term is the difference in consumption between the two states, and this is almost always ignored in empirical work. To the extent that consumption in the ill-state falls short of consumption in the well. state, that difference should be subtracted from a willingness-to-pay measure. To the extent that was true, the "pain and'suffering" term would be offset.

To understand this last adjustment a little better, write the two components combined:

$$(u(c_2,L_2) - G(c_1,L_1))/m - c_2 + c_1$$

$$= \{[u(c_2,L_2) - m\ c_2] - [G(c_1,L_1) - m\ c_1]\}/m.$$

Now m equals the marginal utility of consumption in each state, by the first order conditions of the maximum problem, and can be thought of as the shadow price of consumption in each state. Then each of the terms in square brackets above is total utility in the state minus the utility cost of consumption in that state, or a measure of "rent" in that state. It is the difference in these rents between states that must be imputed to the valuation of morbidity. It seems clear that the rent in the well-state would exceed that in the ill-state, so foregone earnings and medical bills would understate the true cost of morbidity. The extent to which it would understate the truth, however, would depend on the precise properties of preferences and how the illness affects $G(c,L)$.

4.3.5. Value Of Life Expectancy: Stochastic Model

4.3.5.1. Preliminaries

In this section we examine a stochastic decision problem in which life expectancy is uncertain. While this changes some of the details of analysis, the main thrust of the deterministic model carries through with minor alternations.

Analysis of the stochastic case requires some attention to the statistical description of life chances, and a brief review of some actuarial concepts for describing probability distributions over length of life. Let F(t) be the probability of surviving until age t at most. Then 1 - F(t) is the survivor function, the probability of surviving to at least age t, or more. Define $f(t) = dF(t)/dt = -d(1-F(t))/dt$ as the density function of length of life; the probability of surviving to age t exactly. The age specific death rate or hazard rate, is the probability of death at age t given that one has survived up to that age. It is a conditional probability: Denoting the hazard or death rate at age t by h(t), it is $h(t) = f(t)/(1-F(t))$, or from the relationship above:

$$\text{(4-26)} \qquad d\log(1-F(t))/dt = -h(t) \ .$$

Integrating (4-26) and using the boundary condition $F(0) = 0$ (we are only looking at survivors at birth), yields the fundamental relationship between the hazard rate and the survival rate

$$\text{(4-27)} \qquad (1 - F(t)) = \exp\{-\text{ integral from 0 to t of } h(z)dz\},$$

where exp means the exponential $\underline{e}$.

The importance of equivalence (4-27) lies in its relation to the problem at hand. The hazard h(t) is naturally associated with the undertaking of risks to life and is the natural primitive for studying the valuation of life-threatening actions. However, the survivor function is the natural primitive for studying expected utility and expected wealth. Equation (4-27) shows precisely how the two are related.

At some cost of realism, great simplicity in understanding the nature of the problem is achieved by studying some special cases. In particular, assume $h(t) = h$, so the death rate is constant at all ages (the case of constant hazard). Then it follows directly from (4-27) that

$$\text{(4-28)} \qquad F(t) = 1 - e^{-ht},$$

$$1 - F(t) = e^{-ht},$$

$$f(t) = he^{-ht}.$$

The probability density of length of life f(t) is exponential in this case. Furthermore, life expectancy itself, call it E(t) is simply related to the death rate as

$$E(t) = \text{integral from 0 to infinity of } tf(t)dt$$

$$= \text{integral from 0 to infinity of } hte^{-ht} = l/h.$$

$$= l/h.$$

Note that life expectancy is independent of current age in this case. No matter how long one has lived there is always 1/h years left! The system has no memory. This is of course highly unrealistic, but the convenience of analysis more than makes up for this defect. The more general case in analyzed by Arthur, to which the reader to referred for details.

Suppose now that the hazard rate is a step function. That is, it is $h(t) = h_1$ for $t < T$, but then jumps to a higher level beyond some age T: $h(t) = h2$ for $t \geq T$. Then application of (4-27) yields

$$(4\text{-}29) \qquad 1 - F(t) = \exp(-h,t) \text{ for } t < T$$

$$= \exp\{[(h_2 - h_1)T] - h_2T\}.$$

Now the survival function is exponentially declining at rate h_1 for $t < T$, but its slope shows a point of discountinuity at T. It declines at a larger rate for $t > T$ than for $t < T$. Here we would find that life expectancy is decreasing with age, so long as $t < T$.

Any pattern of h(t) could be approximated in this way as a sequence of step functions. Since the mechanics of this are straightforward, they will be omitted here. Instead we turn to the choice problem.

4.3.5.2. Optimal Choices

The fundamental method follows the deterministic approach above. Let us begin by ignoring work decisions and describe tastes by an intertemporally separable utility function in the sequence of consumption c(t). If a person lives exactly t years then his utility is postulated to be

$$U(t) = \text{ integral from 0 to infinity } u(C(z)\, e^{-at}\, dz,$$

which follows precisely the form of the deterministic model. However, in an uncertain world a person lives t years only with probability f(t). Therefore apply the expected utility theorem to U(t). A person's expected lifetime utility is

$$(4\text{-}30) \quad EU = \text{ integral from 0 to infinity of } U(t)f(t)dt$$

$$= \text{integral from 0 to infinity of } u(c(z))e^{-az} \text{ dzdt}$$

$$= \text{integral from 0 to infinity of } u(c(t))e^{-at}$$

$$= \text{integral from 0 to infinity of } f(z)dzt$$

$$= \text{integral from 0 to infinity of } (1-F(t))u(c(t))e^{-at} \text{ dt,}$$

where the second to last equality follows by a change in the order of integration. We see that the relevant utility expression incorporates the survival rate l-F(t) and that is why it is a fundamental concept for the problem. Substituting from above, preferences follow

(4-31) EU = integral from 0 to infinity of

u(c(t)exp(- at - integral from 0 to T h(z)dt)),

so the hazard rate works exactly like a discount rate. To make this even more transparent, suppose h(t) = h is constant. Then EU = integral from 0 to infinity of uc(t))$e^{-(a+h)t}$ dt. and the "effective" discount rate is a + h. The force of mo'rtality h makes a person act more "impatiently" and to weigh the future less heavily.

Budget constraints in problems such as this create a host of conceptual difficulties revolving around the question of how to cope with the fact that the person might die in debt. These issues have been thoroughly explored by Yaari and there is little to add to that discussion here. Hence we adopt a natural solution in which a person is not allowed to die in debt and can borrow and lend on a perfect capital market at rate of interest r. The constraint of budget balance at each possible point in the life cycle is enforced by an actuarial insurance-debt system. It amounts to the following. Whenever a person makes a loan he is compelled to at the same time take out an insurance policy of equivalent value such that if he dies at any time during the course of the loan, the insurance indemnity is sufficient to pay off the remaining balance. As is well known, this is basically an actuarial annunity system in which a cohort of identical individuals turn over their wealth to the insurance-finance company and contract for their optimal consumption bundle c(t) which persists as long as and for however long they live. Those who die early effectively subsidize the fund ex post, since their assets have exceeded their consumption claims. These subsidies are used to pay the consumption claims of those individuals who survive longer than average. We can represent this in a simple manner as follows.

If a person lives for exactly t periods and contracts for c(z), the present discounted value of his claims is integral from 0 to t of c(z)e^{-rz}dz. The probability of surviving for exactly t periods is f(t), so the expected discounted value of the claim c(z) is equated to the person's initial wealth W under an actuarial, no-load system. The budget constraint is

(4-32) W = integral from 0 to infinity of f(t) times

integral from 0 to t of c(z)e^{-rz} dzdt

= integral from 0 to t of (1-F(t))c(t)e^{-rt} dt, where the second equality follows from the same change in order of integration as above. Again, it follows that the influence of the survival term (l-F(t)) in this expression is to increase the effective discount rate. It is interesting to note that even if r and a are zero, there is a well defined optimization problem, something that isn't true in a deterministic problem with an infinite horizon (because the objective function becomes unbounded in that case).

The economic problem is to choose c(t) to maximize (4-30) subject to the constraint in (4-32). Associating a multiplier m with the constraint and noting that the term in (l-F(t)) is common to both the objective function and the constraint and therefore factors out of the optimality conditions, first order conditions for the problem duplicate those of the deterministic problem. We have

(4-33) $$u'(c(t))e^{-at} = m\, e^{-rt} \text{ for all } t.$$

The interpretation is straightforward. The life insurance features of the annuity arrangement allow the person to do whatever he would have done in the deterministic problem and to insure the death risk over consumption streams by the law of large numbers applied to his cohort. In particular, assume r = a. Then (4-33) implies c(t) = c, a constant, and the person contracts for a constant-consumption stream up to the point of his death and no matter how long he lives. From the budget constraint we have that c = W/integral from 0 to infinity of $(1-F(t))e^{-rt}$ dt, so the amount of consumption available under this scheme depends on the person's wealth, the rate of interest, and the precise age-pattern of survival probabilities.

4.3.5.3. Valuation Formulas

Consider the case where h(t) = h. Then (4-32) implies W = c/(r+h), just the formula for the value of a perpetuity of c at discount rate (r+h). In this case (4-30) becomes EU = EU = u(c)/(r+h), or instantaneous utility discounted at rate r+h forever. Therefore

(4-34) $$V = EU = u(W(r+h))/r+h \ .$$

This looks very similar to the deterministic problem. Define v' as the value of changing the probability of death, h. Then

(4-35) v' = - (partial of V w.r.t h)

/ partial of V w.r.t. W = dW/'dh.

v' is amount of money the person would have to be paid to increase the death rate confronting him by dh. From (4-34)

$$V_W = u'(c),$$

$$V_h = [(r+h)Wu'(c) - u(c)]/(r+h)^2 .$$

Therefore, in the constant hazard case with $r = a$,

$$(4\text{-}36) \qquad v' = [u(c)/u'(c) - (r+h)W]/(r+h)^2$$

$$= (W/(r+h))(1-E)/E,$$

where again E is the elasticity of u(c) with respect to c, and $0 < E < 1$. Comparing this with equation (4-11) of the deterministic model, we see that the term in h serves as the correction factor for finite life, rather than the annuity term A in (11). Otherwise, the expressions are identical and have identical implications. v is increasing in W and decreasing in E for the same reasons as were spelled out above. In particular, the role of quantity versus quality of life substitution as reflected in E remains exactly the same as before. It is also true that v' is decreasing in r, and is also decreasing in h.

We can find an equivalent expression in terms of the expectation of life, $\bar{t}$, since $\bar{t} = 1/h$ when the hazard is constant. Then $dh = - d\bar{t}/\bar{t}^2$ so

$$dW/d\bar{t} = [(W)/\bar{t}(r\bar{t}+1)]\,[(1-E)/E].$$

A person with a longer life expectancy is willing to pay less to extend it.

4.3.5.4. Valuations of Workers

Let us now extend the stochastic model to include choice of work and earnings as well as consumption. Then, similarly to the deterministic models, the one-period utility function must be written $u(c,L)$, where L is leisure. This function replaces u(c) in the definition of expected utility in (4-30). A worker has a source of earned income as well as endowed wealth. If he can earn w(t) per unit of time, earned income is w(t)(1-L(t)), which when discounted to present value and including allowances for mortality becomes infinity of 0 to infinity of $w(t)(1-L(t))(1-F(t))e^{-rt}dt$ and which must be added to the term in W on the left hand side of the budget constraint in (4-32). The first order conditions for choice of c(t) and L(t) duplicate equation (4-14) in the deterministic model. With $r = a$ and $w(t) = w$, the value function becomes

(4-39) $$V = \max_{c,L} \{[u(c,L) + m[w(1-L) - c]]$$

$$\text{integral from 0 to infinity of } (1-F(t))e^{-rt}\, dt + m W),$$

since $c(t) = c$ and $L(t) = L$ under these circumstances.

Assume $h(t) = h$. Then the integral term in (4-39) is merely $1/(r+h)$ and maximum expected utility is the perpetuity value of $u(c,L)$ held at its optimal values of c and L, at discount rate $r+h$. In this case we find

(4-40) $$-V_h / V_W = [c(1-E)/E + w(1-L)]/(r+h)^2$$

as the capital sum the person would be willing to give up to reduce the death rate by dh. This expression is similar to (4-36) with the addition of the earned income term; since the opportunity to work has value.

Expression (4-40) does not closely relate to empirical work in this area. Much of the empirical work on the value of life uses labor market data and estimates the risk premium necessary to induce a worker to undertake a risky job. For the problem at hand, the relevant risk premium is nothing more than $-V_h / V_w$, which is, in this case

(4-41) $$-V_h /V_w = [c(1-E)/E + w(1-L) - c]/(1-L)(r+h).$$

From this expression we may infer something about the intertemporal substitution parameter E.

As an example, consider the study of Thaler and Rosen (Ippolito and Ippolito produce a similar estimate from much different data.) Thaler and Rosen estimate $- Vh /V_w$ in terms of the weekly wage as $3,520 in 1968 dollars. In their sample average weeks worked are approximately 50 and the average worker earned about $6,600. Since this is a low income population, the bulk of consumption expenditure must have come from earnings, so ignore savings and assume $c = w(1-L) =$ $6,600. Substituting this and $(1-L) = 50$ into (4-41) and rearranging, we have

$$E = (6{,}600/176{,}000) / (r+h) .$$

Hence the estimate of E depends on assumed values of r and h. In the Thaler and Rosen sample, h is about 2.5 per 1,000, decomposed into 1.5 per 1,000 normal life table experience plus an additional 1.0 per 1,000 excess risk from working conditions among people in hazardous jobs. Hence any realistic interest rate swamps the effect of h. For this population $r = 10\%$ would appear to be a plausible lower bound. If so than E = .39. If r = 15% the estimate of E drops to .26. Presumably these are upper bound estimates among the population at large, because most workers are not found in risky jobs through selection: ceteris paribus their value of E must be no greater and most probably lower than indicated if they find it advantageous to work on safer jobs at lower rates of pay. Hence from this evidence, we get an upper bound of E in the .25-.40 range.

Now return'to equation (4-36) and convert it into logs:

$$\text{(4-42)} \qquad d\log W/d\log h = [h/(r+h)](1-E)/E.$$

Substituting the values above yields as estimate for dlog W/dlog h in the range .04 to .05. That is, the people in this sample would have been willing to give up one-half percent of their wealth for a 10 percent reduction in the death rate. Presumably the equivalent sum for the average person in the population is larger than this because of the selection effect mentioned above. Notice however, that the term in $h/(r+h)$ is even smaller for such persons (because their values of h are smaller) and this dampens any effect of a smaller value of E. Notice also, as a rough and ready approximation, the term in h would be much larger for older persons, so they would be willing to pay a much larger fraction of their wealth.

Now consider an experiment related to the specification in (4-29). This is interesting because it is closely related to long term hazards with a latency period of length T. Thus, for example, a person with a "normal" risk exposure h_1 may undertake some action now which has no effect on death probabilities until periods later, at which time the death rate jumps to h2. Exposure to chemical substances may take this form. Again maintaining r = a for simplicity, from (4-29) and (4-30) and (4-32) we have

$$\text{(4-37)} \quad v = \max\ (u(c) \text{ integral from infinity of } (1-F(t))e^{-rt}\, dt$$

$$+ \quad m[W - c \,/\, (1-F(t))e^{-rt}\, dt]$$

$$= \max\ [u(c) - mc][(1/(r + h_1))(1-\exp-(r+h_1)T)$$

$$(1/(r+h_2))\ (\exp\ (-(r+h_1)T),$$

from which it follows by the now familiar manipulations

$$(-V_{h_2})/V_w = [c((1-E)/E)\exp\ (-(r+h_1)T)]/\ [(r+h_2)^2]$$

(4-38) $$V_T/V_W = [c((1-E)/E)\exp(-(r+h_1)T)]\,[(h_2-h_1)/(*r+h_2)]$$

$$V_T/V_{h_2} = (h2 - h_1)(r + h_2) .$$

The first expression in (4-38) shows how much the person is willing to pay to reduce the later hazard. This again depends on the intertemporal substitution parameter E and the level of consumption, as before. It also depends on how far away the hazard is from the present--the further away it is the smaller the willingness to pay to reduce it--and on the rate of interest. The second expression in (4-38) shows how much the person would be willing to pay to push the increased hazard a little bit further away from now. This also depends on c and E, and is decreasing in T and increasing in the difference $h_2 - h_1$. The third expression, written for completeness, is the marginal rate of substitution between the level of the new hazard and the time of its occurrence.

The most important thing to notice about these valuations is that they are time or age dependent. The willingness to accept risks of this form is largest for younger people and the willingness to pay to avoid them is largest for older individuals (when the person is old enough to have passed beyond $t = T$, the formulas revert to the form of (4-36)). This is basically due to the force of discounting, which includes not only the interest rate but the hazard rate itself. Furthermore, these expressions make no allowance for pain and suffering and the manner of death, but including such factors would have the effect of increasing their absolute values without affecting their intertemporal patterns.

Changing valuations over the lifecycle raises some tricky issues for risks that are irreversible. Thus suppose the market provides an opportunity for undertaking a risk exposure of the type above which increases wealth or utility in other ways. Then we would again find some critical age, beyond which a person would not undertake the risk, but before which he would. Suppose this action affects h_2 permanently, so there is no going back on the decision once it has been undertaken at the early age, and the person is stuck in a permanently high risk class at some time in the future. Then as the person ages, he would perhaps have ex post regret about his earlier actions. However, there appear to be no inconsistencies (in the sense of intertemporal irrationalities) in this type of behavior, because, by hypothesis, all these affects are foreseen in the first instance. The point applies to any type of gambling behavior. A gamble may appear to be very favorable ex ante, but ex post realizations often lead to regret, about which nothing can be done and which is already factored into the initial decision to undertake it. The same is true in this case when all the information is on the table.

Nonetheless, in evaluating such hazards for the purposes of social policy and cost-benefit analysis, one would certainly like to take account of different valuations by people of different **ages**, since it is the sum of all valuations whichmatter. That a person might have a different valuation at different points of time and age is properly accounted for in these sums, and no allowance need be made for the fact that the person will change his valuation at some future time. This conclusion is of course conditioned on the manner in which the problem has been set up, which assumes perfect information and a perfect capital market. If capital markets were imperfect and the insurance charge did not fully reflect the increased future risk for any given person, there would be a moral hazard effect and the social value of risk would exceed the private value, because individuals would have a tendency to shift risks excessively to the insurance fund. Too many risks would be undertaken. And of course similar statements apply if assessments of future hazards are biased (in either direction) by the persons undertaking them.

4.3.6. Interpretation and Applications

4.3.6.1. Major Results From The Life Cycle Model

Section 4.3 has been motivated by the question "How much of the economy's wealth should be spent on safety, health and longevity concerns?" The answer depends on the way individuals (or households) appraise their own life situations. and how they make decisions they judge to be optimal in light of those situations. This section has provided a framework that identifies the underlying decision variables and guides the valuation of policy decisions designed to improve people's life prospects.

A life cycle frameworkhas been seen to be appropriate, and the intimate relation between quality of life and longevity, or quantity of life, has emerged in the **development** of the model. Valuations of increases in life expectancy, in reductions in periods of illness, and in reductions in risk of death have been explored. Labor force participation and the value of increased longevity are taken into account. Results derived from the model include widely recognized effects such as foregone earnings and medical expenditures, and also more frequently overlooked effects such as the utility of consumption and leisure and differences in the utility of consumption and leisure and differences in consumption between various states of wellness.

Several parameters play key roles throughout the development of the model, and others are important to the development of special parts of it. Perhaps of greatest interest among the former is the elasticity of lifetime consumption. This relates to intertemporal substitution and reflects the close relationship between the quality and quantity of life. Other parameters in this category are the rates of interest and time preference, the level of wealth and the person's stage in the life cycle.. Of interest in the other category of parameters, pertaining to special parts of the model, is a "consumption correction factor," which takes into account the fact that people's capacities change over their life cycles. This is particularly important, in empirical work because it pertains to people's endowments, which are important in explaining their valuations. Another special parameter is the hazard function parameter, which measures an individual's probability of dying at any given age. This is another aspect of endowment. It is central to the treatment of the effects of uncertainty on choice and is of particular interest in valuing threats to health that involve latency, which is represented by a discrete increase in the hazard of death after a number of years elapse.

One of the results is that younger prople are willing to pay less to extend their lives than older people. The primary reason is that the return to a younger person is deferred so far into the future that its present value has been largely wiped out by discounting. It is quite possible that the person when older will regret actions taken earlier in life because extended longevity has become more important in the meantime. Nevertheless the now regreted actions must be regarded as rational when preferences are time separable. A similar result is obtained in the analysis of risks to health which change the probability of death after an intervening period of latency. Once again the farther into the future the increased risk is deferred the less a person is willing to pay now for its reduction.

Maureen Cropper has added a comment regarding the effects of age on willingness to pay for risk reduction. One must distingusih between the age of the respondent at the time the question is asked and the age at which the risk occurs.

To illustrate, consider two men, one 18 and the other 45, who have identical preferences and lifetime earnings streams. The distribution of date of death conditional on reaching age t (t-18,...) is the same for both persons. The only difference between them is that the 45-year-old has followed for 27 years the consumption path which the 18-year-old will eventually follow. There are three willingness to pay to compare:

(1) The amount the 18-year-old will give up today to avoid a marginal increase in his conditional probability of death at age 18.

(2) The amount the 18-year-old will give up today to avoid a marginal increase in his conditional probability of death at age 45.

(3) The amount the 45-year-old will give up today to avoid a marginal increase in his conditional probability of death at age 45.

With perfect annuities markets and a rate of time preference equal to the market rate of interest, (1) > (2) and (1) > (3). The fact that (1) > (2) means that a reduction in risk of death 27 years hence is less valuable than a reduction in current risk of death. This point is made in this section and has obvious relevance for valuing risks with long latency periods.

The fact that (1) > (3), i.e., that the 18-year-old will pay more to reducehis _current_ risk of deaththanthe 45-year-old (at least according to the theoretical model) needs to be made clearly. One can reverse this inequality by assuming imperfect capital markets, which constrain the individual to consume no more than his income when he is young, and a hump-shaped earnings stream; however, under the assumptions of this section, (1) > (3).

V. Kerry Smith comments "on the possibility of considering a'changing framework,' that is, a framework which allowed the individual to change his or her plans over time. The current framework seems to assume there is one optimal plan which is in not allowed to change with respect to changes in the parameters of the individual's situation. The actual model is probably much more like a situation in which the individual makes a plan and then takes one step along that plan, updates, and utilizes a new plan."

The elasticity of the life cycle consumption function, which is closely'related to the intertemporal substitution of consumption, has a strong bearing on both the value of extended life and the value of reducing hazards that occur later in life. The greater a person's ability to substitute present consumption for future consumption the less interest that person has in providing for the future. The value of the intertemporal substitution parameter is a key importance in understanding tradeoffs between the quantity and quality of life in this framework.

Elasticity of consumption is estimated to have an upper bound of 0.25 to 0.40. This rather low elasticity implies that quantity and quality of life are poor substiutes for each other, which in turn varies the value of extra years of life.

Allowing for reduced capacity for consumption during later years of life requires a consumption correction factor. The implication of diminishing capacity is that unless real consumption can be maintained the value of longevity is reduced. This is an important implication because people's consumption-capacity prospects and expectations can be approximated empirically.

The fact that people value extensions of life the older they get has implications for labor market behavior. Supposing that opportunities to extend life a given amount have a constant cost independent of age, then there is a threshold age belov which people are willing to accept shortened life expectancy in exchange for increased money return, whereas people above the threshold will not accept the trade.

Application of the framework to some available sample evidence yields the result that people would give up one-half percent of their wealth for a ten percent reduction in the death rate. The equivalent amount for an average person in the population would probably be greater.

4.3.6.2. Life Experiences and the Willingness to Pay to Avoid Serious Illness

The life cycle approach to serious illness was applied in later parts of this study in experimental focus group sessions. It was hypothesized and found to be the case that age makes a great difference in the way a person perceives the consequences of risks to health, either with certainty or varying degrees of probability. Focus group explorations of hypothetical life path experiences showed graphically that people in their twenties have little or no interest in their health propsects for their seventies or even their fifties. A different picture emerges from the responses of people in their fifties or sixties. The theoretical contributions of this section provide the rationale for this behavior and point the way to empirical solutions to the problems raised by these focus group encounters.

The contingent valuation questions to be considered in Section 4.5, which grew out of the framework here and learning from focus group experience, emphasize comparisons between life paths. In some cases individuals are required to rank alternative paths which embody different tradeoffs between suffering and life expectancy. Different kinds and durations of suffering are considered. Finally, uncertainty is introduced and valuations of risks are sought within streams of experience that embody both sickness and death.

Perfect health is generally not the alternative to symptoms, diseases or health risks that are reduced by successful public policy. The value of improved prospects must be weighed against alternatives that carry risks of their own. Thus a person is generally trading one stream of illnesses for another, less undesirable one. It is this change, rather than a transition to perfect health, that constitutes the benefit of the public policy.

The life path approach constitutes in a number of ways a departure from conventional methods of valuing health benefits. The distinguishing feature of the approach is its treatment of the whole stream of experience as the focus of analysis. Good health, illness and death are viewed as inseparable in analysis as in life. As in other areas of life people make choices for more or less health and longevity. To an important degree people choose greater or lesser amounts of health and longevity depending on their values for these goods relative to their other wants and needs. The life path approach is an appropriate means of obtaining health values because it is based on willingness to pay in view of the totality of substitutions that people make over time in resonse to changes in health risks. Methods that attempt to value health or longevity as one period events, and especially methods that disregard age, run the danger of missing important determinants of health values.

4.3.7. References

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